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# RESPONSE OF GEOGRAPHICAL STRAINS OF GRASSES TO LOW TEMPERATURES[1]

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OUT of approximately 1,500 accessions of grasses studied at the Northern Great Plains Field Station, Mandan, N. Dak., from 1936 to 1941, 40% failed to survive the extreme climatic conditions. The majority of these grasses were species and strains of importance occurring naturally within some portion of the Great Plains region. They failed to survive primarily because of winter injury. This fact emphasizes the need for more studies pertaining to adaptation before particular strains or species are recommended for widespread use.

These investigations were carried on in the field at Mandan, N. Dak., and in the greenhouse and low temperature research laboratory at the University of Minnesota. The purpose of this study was to obtain information on the resistance to low temperatures of seedlings and mature plants of geographical strains of grasses.

## REVIEW OF LITERATURE

Since this study takes up the effect of cold temperature on geographical strains of grasses, it seems desirable to review some of the literature pertaining to the general distribution of geographical strains of plants and their variation in nature, as well as literature bearing more directly on freezing studies.

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[1]Field data were obtained through cooperative investigations of the Division of Forage Crops and Diseases, the Division of Dry Land Agriculture, Bureau of Plant Industry, Agricultural Research Administration, and the Nursery Division, Soil Conservation Service, U. S. Dept. of Agriculture. Laboratory data were obtained through cooperative investigations of the Division of Forage Crops and Diseases, Bureau of Plant Industry, Agricultural Research Administration U. S. Dept. of Agriculture, and Division of Agronomy and Plant Genetics, University of Minnesota. Received for publication February 6, 1943.

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Arny (2)[3] found that strains of medium red clover produced in France, Chile, and Italy winterkilled 81%, 89.5%, and 93.9%, respectively, during the winter of 1922–23 at St. Paul, Minn. Strains from northern Europe killed much less, and those from north central and north inter-mountain states in this country gave low percentage of winterkilling.

Law and Anderson (6), in working with *Andropogon furcatus* Muhl., point out that this species exhibits a wide range of adaptation to many soil types and to a variety of climatic conditions. Strains from Nebraska, Kansas, and Oklahoma grown at Manhattan, Kans., indicate definite ecotypes which have developed as a result of natural selection over a long period of time. In general, the northern plants were earlier, smaller, and less leafy than those of southern origin, while the plants from Kansas were intermediate in these characters. The heading date of the Nebraska plants was 21 days earlier than that of the Kansas plants, while Oklahoma plants headed 47 days later than those from Kansas.

It will be brought out in the discussion that all warm temperature species studied tend to become dormant in the fall regardless of how high or optimum the temperature is maintained, while the cool temperature species do not show this tendency. Shepherd (11) has shown that *Andropogon furcatus*, *Bouteloua curtipendula* (Michx.) Torr., and *B. gracilis* (H.B.K.) Lag. remain dormant for the greater part of the winter and will not grow though given an artificial climate with optimums of temperature and light duration. If the rest period is broken by freezing, vegetative growth will be produced. He pointed out also that *Agropyron smithii* Rydb. does not become dormant when transplanted to the greenhouse in the fall.

Studies of the nature of frost resistance in plants are voluminous. Recent reviews have been made by Harvey (5), Levitt and Scarth (8), and Levitt (7). Excellent early reviews were made by Abbe (1), Chandler (3), and Harvey (4).

Previous investigations by many workers on methods of artificially freezing various species were used as a working guide in setting up the related portion of the present study.

Shultz (10) exposed 66 clonal lines of 2-year selfed plants of *Dactylis glomerata* L. that had been grown in the greenhouse to a 12-day hardening-off period at 2° C. They were then frozen at −10° C for 24 hours and thawed at 2° C for 40 hours before being returned to the greenhouse. The analysis of the results showed a highly significant difference in the reaction of various clones to artificial freezing even though all clones had originated from plants that were relatively winterhardy in the field. Clones from commercial plants unselected for winterhardiness were frozen under the same conditions. These clones as a group were more severely injured by freezing than the selected selfed clones. In testing the association between field hardiness of the selfed clones and their reaction to artificial freezing, he found that no correlation existed. In his field hardiness tests winterhardy parents showed a tendency to produce winterhardy selfed progenies. Strains from Germany, Wales, and New Zealand were also tested and found to be low in winterhardiness, while those from local collections and from Canada ranked high in winterhardiness.

## MATERIAL AND METHODS

The species used in this study are grouped into two broad classifications based on the period of maximum vegetative growth. These groups are called "cool

[3]Figures in parenthesis refer to "Literature Cited", p. 559.

temperature species" and "warm temperature species". Cool temperature species are those which make their maximum vegetative growth during the spring and fall with a lesser amount of growth during the hot part of the summer. These species start growth very quickly after the ground thaws out in the spring and if moisture conditions are favorable in the fall they continue growth until late in the season. The warm temperature species make their maximum growth during the summer season and at Mandan, N. Dak., start their spring growth approximately 3 weeks after the cool temperature species. They cease growing with the advent of the first hard frost in the fall.

The cool temperature species used in the study of reaction to artificial freezing were *Agropyron cristatum* (L.) Gaertn., *A. smithii* Rydb., and *Bromus inermis* Leyss. Three geographical strains of each species were used, and in addition, the standard strain of *A. cristatum* was used as a check.

All species are of major importance in the Northern Plains. All are highly cross-pollinated and show wide variability. No reports of winter injury to establish stands of any of these species have been made. *Agropyron cristatum* and *B. inermis* have been grown successfully as far north as Whitehorse, Yukon, where temperatures as low as –60° F have been recorded. All strains of *A. cristatum* used in this study originated in the north, except No. 1227, which was grown in Nebraska and is of unknown origin. These strains were all of the commercial standard type, except No. 96–24 and No. 23 Fairway. No. 96–24 is a large-seeded, awnless, standard-type strain, which produces larger, more vigorous-growing seedlings than the other strains studied. The Fairway strain is distinctly different in growth character and has a somatic chromosome number of 14, while the standard type has a somatic number of 28 chromosomes (9). Both the seed and seedlings of Fairway are smaller than those of the standard variety.

Bromegrass strain No. 1253 has been grown in Nebraska and northern Kansas for approximately 40 years. The Parkland strain was developed at the University of Saskatchewan (12) and No. 1250 was a commercial strain from North Dakota. All *A. smithii* strains were bulk collections.

Warm temperature species used in the study of reaction to artificial freezing were *Andropogon furcatus* Muhl., *Bouteloua gracilis* (H.B.K.) Lag., *B. curtipendula* (Michx.) Torr., and *Panicum virgatum L.* Three geographical bulk-collected strains of each species were included in the study. These warm temperature species are all native grasses of major importance and occur over a wide geographical range. They are also cross pollinated and widely variable.

At the beginning of the grass improvement program at Mandan, N. Dak., in the spring of 1937, seed of a large number of geographical strains of the major Northern Plains species was assembled and planted in the greenhouse. Individual plants were then transplanted to the field. The individual plants were established on very uniform soil and spaced 42 inches apart in each direction with 40 plants to a row. Each spring after growth had started, careful counts were made of the number of plants that were completely killed and of those that were partially killed. The partially killed plants had suffered winter injury but were not completely dead.

In the field studies it was assumed that differences in survival were due primarily to cold injury. No severe droughts occurred during the period and since the plants were spaced 42 inches apart in each direction, moisture conditions were such that plants could make maximum growth. This being the case, danger of injury from dessication was slight. The minimum temperature during the 4-year period was –34° F on February 14, 1939. The greatest snowfall for any one

month was 12.9 inches in February 1938. Snow cover played some part in protecting the plants. In most cases the covering was light and uniformly distributed over the entire area.

Under conditions at Mandan, survival of spaced plants of the species in this study might, in some cases, be somewhat different from survival in solid stand seedings. Spaced plants do not offer as much mutual protection as plants in solid seedings. However, the more plentiful soil moisture in spaced plantings and consequent increase in plant vigor tend to offset this lack of mutual protection. Observations on the survival of plants in solid seedings indicate that survival data from spaced plants are a good index of the survival that may be expected from solid seedings of the same strains. For the purposes of this study the use of spaced plants made it possible to determine actual percentages of killing.

On August 25, 1941 two individual plants from each geographical strain to be frozen artificially were dug and divided clonally and established in the greenhouse. After a period of hardening for 7 days at 2° to 4° C, these clones were frozen at different ages and at various temperatures, as will be brought out in the discussion.

Seed of three strains each of cool temperature species and four warm temperature species was planted on August 27, 1941, and seedlings transplanted to flats on September 24. Twelve replications each of the warm temperature and cool temperature species, respectively, were transplanted with one flat containing a replication. All geographical strains of warm temperature species were included within each of the 12 flats of warm temperature species. In like manner all strains of cool temperature species were represented within each of 12 flats of cool temperature species. Commercial *Agropyron cristatum* was used as a check in all cases with both the warm and cool temperature species. Each strain was represented by a row of 10 seedlings. The rows were randomized within each flat and were transplanted approximately 2 inches apart. Each flat of cool temperature species contained 12 rows including three check rows, and each flat of warm temperature species contained 14 rows including two checks. Another series of 12 replications of both warm and cool temperature species was seeded on September 24 and handled as previously described. A day length of approximately 14 hours was maintained in the greenhouse at all times by using light from incandescent lamps as a supplement to natural daylight.

All seedlings were hardened for 7 days at 2° to 4° C before being subjected to freezing temperatures. Two 200-watt incandescent lamps were kept burning in the hardening chamber to keep the plants from becoming etiolated. After freezing, the flats of seedlings were allowed to thaw for 48 hours at 2° to 4° C before being returned to the greenhouse. Preliminary tests gave a basis for estimating the temperatures at which the seedlings should be frozen to get differential killing. Seedlings of different ages were then frozen at various temperatures for different periods of time. In all cases notes were taken before freezing on the number of seedlings to a row, height, leaf stage, and vigor. After freezing, notes were taken on several dates, on freezing, injury, and vigor.

In each study the survival percentage was determined for each row in each replication. Means were obtained by averaging the results of all replications for each treatment. Standard errors of these means were calculated separately for each treatment. Standard errors of the differences were then calculated to determine the significance of these differences for the various comparisons that were made. In this study the 5% point was used as the level for significance and the 1% point as the level for high significance. It is known that there was probably some association between seedling survivals in the various comparisons, but it was

assumed that the correlation was zero. In many cases the number of variates making up the means was different and paired comparisons could not be made. If there had been a correlation of zero, then the value necessary for significance would have been the same in both the paired and unpaired relationships.

## EXPERIMENTAL RESULTS

### FIELD SURVIVAL

Geographical strains of the warm temperature species, *Bouteloua gracilis*, *B. curtipendula*, *Panicum virgatum*, and *Andropogon furcatus*, were studied for winter survival in the field at Mandan, N. Dak., from 1937 to 1941. After the winter survival of each strain was obtained, the data for strains of each species within geographical regions of the Great Plains were grouped together. Table 1 gives the data obtained for the four species within the Northern, Central, and Southern regions. Strains from North Dakota were included in the Northern region; those from Nebraska, Iowa, Wyoming, and northern Colorado in the Central region; and those from southern Kansas, Oklahoma, Texas, New Mexico, and Arizona in the Southern region.

TABLE 1.—*Winter survival of geographical strains of Bouteloua gracilis, B. curtipendula, Panicum virgatum, and Andropogon furcatus at Mandan, N. Dak., for the period 1937 to 1941, inclusive.**

| Great Plains geographical region | No. of accessions | No. of plants fall of 1937 | Percentage survival winter of | | | | Percentage of surviving plants showing winter injury winter of | | | | Degree of injury to surviving plants† |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1937–38 | 1938–39 | 1939–40 | 1940–41 | 1937–38 | 1938–39 | 1939–40 | 1940–41 | |
| | | | | | *Bouteloua gracilis* | | | | | | |
| Northern | 5 | 158 | 100.0 | 100.0 | 100.0 | 100.0 | 5.1 | 5.7 | 22.2 | 7.0 | 0.8 |
| Central | 5 | 186 | 99.5 | 99.5 | 99.5 | 99.5 | 34.1 | 22.7 | 81.6 | 77.8 | 2.6 |
| Southern | 7 | 207 | 50.7 | 47.8 | 46.9 | 41.1 | 62.9 | 55.6 | 97.9 | 96.5 | 4.0 |
| | | | | | *Bouteloua curtipendula* | | | | | | |
| Northern | 7 | 214 | 100.0 | 99.5 | 99.5 | 98.6 | 6.1 | 12.7 | 20.2 | 9.5 | 1.0 |
| Central | 4 | 121 | 100.0 | 98.3 | 98.3 | 97.5 | 9.1 | 11.8 | 64.7 | 59.3 | 2.8 |
| Southern | 7 | 180 | 72.8 | 67.2 | 67.2 | 64.4 | 70.9 | 53.7 | 91.7 | 93.9 | 3.7 |
| | | | | | *Panicum virgatum* | | | | | | |
| Northern | 5 | 181 | 100.0 | 100.0 | 100.0 | 100.0 | 1.7 | 9.4 | 0.6 | 0.0 | 0.0 |
| Central | 6 | 246 | 100.0 | 100.0 | 100.0 | 100.0 | 2.0 | 26.0 | 1.2 | 0.4 | 0.2 |
| Southern | 10 | 449 | 76.2 | 75.7 | 75.5 | 75.3 | 36.3 | 19.4 | 18.9 | 34.6 | 2.4 |
| | | | | | *Andropogon furcatus* | | | | | | |
| Northern | 1 | 26 | 100.0 | 100.0 | 100.0 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Central | 3 | 79 | 100.0 | 98.7 | 98.7 | 97.5 | 21.5 | 3.8 | 17.9 | 31.2 | 1.3 |
| Southern | 2 | 72 | 59.7 | 59.7 | 59.7 | 56.9 | 62.8 | 41.9 | 65.1 | 73.2 | 2.5 |

*All plants established in the spring of 1937.
†An index to injury of those plants still alive with greater numerical value indicating more severe injury. 0 indicates no injury; 4 indicates very severe injury.

It is evident from the data presented that strains of the same geographical origin for the warm temperature species included in the study react similarly to the winter climate. The northern strains are highly winterhardy, but survival decreases as the origin becomes more southerly. *Panicum virgatum* is slightly more hardy than the other three species, but it is not advisable to use strains of even this species from the Central or Southern Plains in the Northern Plains because of their lack of adaptability.

Data obtained on the survival of individual strains showed a marked difference in the ability of different strains to survive the winter even though they originated within the same locality. This suggests the possibility of selecting strains with greater winterhardiness.

A gradual decline in vigor of plants of southern strains which have survived has been apparent. During the first year of growth, the southern strains of the warm temperature species were much more vigorous than northern strains. This was still true in the second season of growth even though winter injury had been considerable. Strong seed stalks and heads were produced the second season. It was evident in the third and fourth seasons that most plants of southern origin had been greatly weakened with an increase in both complete and partial killing. Fig. 1 shows differences in winterkilling and size of geographical strains of *B. gracilis* in 1941. Other warm temperature species show these same general characteristics. A direct relationship in time of maturity was shown between the region from which a southern strain of a warm temperature species was obtained and its period of maturity in the north, the time of maturity being latest for those strains that originated farthest south. There was no apparent difference in time of foliage emergence between geographical strains within any one species.

Large numbers of geographical strains of the cool temperature species studied were planted in the field in 1937. Strains of *Agropyron smithii* from North Dakota, Nebraska, Kansas, and Texas were carefully watched for signs of winter injury but in no case was any observed. Southern strains of this species were in general more coarse, less leafy, and taller than northern types but flowered approximately on the same date, the seed being mature about the last week in July. Foliage emergence in the spring has been approximately the same for all strains regardless of geographical origin. *Bromus inermis* from Kansas, Nebraska, and Canada has shown no signs of winter injury. Here again foliage emergence dates were approximately the same for all strains, as were the flowering dates. Seed was mature during the second week in July for the 4-year period included in the study. *Agropyron cristatum* strains were obtained from as far south as Nebraska, but no apparent difference was shown between these strains and those from North Dakota. No winter injury occurred and seed was mature on all strains during the second week in July. Differences in geographical strains of this species would be less likely to occur because the species has not been introduced into this country long enough for much natural selection to have occurred in the various regions where it is grown.

ARTIFICIAL FREEZING SURVIVAL

Seedlings of warm temperature species, 35 and 65 days old, respectively, were hardened as described and frozen at a temperature of $-18°$ C for a 24-hour period. Six replications were used in studying each age group. Counts made 9 days later showed no survival of any seedlings, except those of the *Agropyron cristatum* check. It was evident that this temperature and exposure were much too severe to show differential killing. Seedlings of the 12 *A. cristatum* checks that were 63 days old averaged 61.46% survival and those 35 days old 50.00% survival. Evidence obtained in this first freezing trial showed the ability of *A. cristatum* seedlings to survive a much lower temperature and greater exposure than those of warm temperature species. Data presented later will show the similarity of the other cool temperature seedlings to *A. cristatum* in their ability to survive cold temperatures. This fact may partially explain why early fall field plantings of warm temperature species are generally unsuccessful while those of cool temperature species are generally successful.

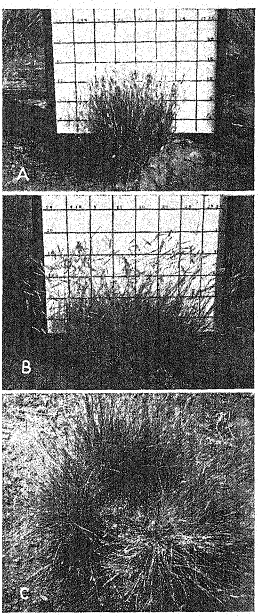


FIG. 1.—Typical plants of geographical strains of *Bouteloua gracilis* grown at Mandan, N. Dak., in 1941. All plants 5 years old. A, North Dakota strain with no evidence of winter injury; B, Nebraska strain with partial killing, also larger and later in maturity; C, Texas strain with greater winter injury and still later maturity.

Good differential killing was obtained when seedlings 69 days old were frozen at $-10°$ C for 9 hours. This is shown in Table 2. *Bouteloua gracilis* and *B. curtipendula* reacted very similarly at this temperature and exposure. There was no significant difference in the survival of North Dakota and Nebraska strains, but both survived better than Texas strains. The Kansas strain of *Andropogon furcatus* gave a higher survival than that from North Dakota, but this was probably due to the greater vigor and more advanced growth of the Kansas strain. *Panicum virgatum* from North Dakota showed higher survival than that from Nebraska and Oklahoma. *B. gracilis* and *B. curtipendula* from North Dakota and Nebraska gave highly

TABLE 2.—*Seedling survival of warm temperature species frozen at two ages at one temperature and for two periods of time.*

| Accession No. | Species | Origin | Percentage survival at −10° C | | |
|---|---|---|---|---|---|
| | | | 69-day seedlings frozen 9 hours* | 41-day seedlings† | |
| | | | | Frozen 9 hours | Frozen 6 hours |
| 8 | *B. gracilis* | Mandan, N. Dak. | 85.56± 5.0 | 0.00 | 15.27± 9.9 |
| 51 | *B. gracilis* | Sidney, Neb. | 93.56± 4.3 | 0.00 | 13.70± 8.9 |
| 669 | *B. gracilis* | Temple, Tex. | 48.12±14.4 | 0.00 | 3.70± 3.7 |
| 952 | *A. cristatum* (check) | Mandan, N. Dak. | 96.66± 3.3 | 96.70± 3.4 | 92.60± 7.4 |
| 99 | *B. curtipendula* | Mandan, N. Dak. | 84.28± 8.0 | 7.40± 7.4 | 44.93± 4.4 |
| 163 | *B. curtipendula* | O'Neill, Neb. | 85.66± 4.3 | 0.00 | 19.43± 4.4 |
| 832 | *B. curtipendula* | San Antonio, Tex. | 19.18±16.0 | 4.17± 4.2 | 6.67± 6.6 |
| 10 | *A. furcatus* | Mandan, N. Dak. | 2.86± 2.8 | 10.73± 6.5 | 29.30±16.8 |
| 152 | *A. furcatus* | Manhattan, Kans. | 29.10±10.8 | 6.67± 3.4 | 10.37± 5.9 |
| 830 | *A. furcatus* | San Antonio, Tex. | 13.50± 7.1 | 0.00 | 17.03± 6.6 |
| 353 | *P. virgatum* | Mandan, N. Dak. | 16.22± 2.3 | 0.00 | 3.33± 3.3 |
| 52 | *P. virgatum* | Sidney, Neb. | 4.00± 2.6 | 0.00 | 6.67± 3.3 |
| 206 | *P. virgatum* | Muskogee, Okla. | 2.00± 2.0 | 0.00 | 0.00 |
| 952 | *A. cristatum* (check) | Mandan, N. Dak. | 100.00 | 100.00 | 96.67± 3.4 |

*Average of five randomized replications.
†Average of three randomized replications.

significant survival over *A. furcatus* and *P. virgatum* from North Dakota, Nebraska, or Kansas.

Another group of seedlings 41 days old was hardened, as usual, and frozen at −10° C for 9 hours. As is shown in Table 2, survival was much lower than that of the seedlings which were 69 days old. In many cases there was complete killing. It was impossible to calculate the standard error of the difference for most comparisons because of the low survival at this temperature and exposure. In those cases where some survival occurred no significant differences were apparent between geographical strains of the same species. When the 41-day seedlings were frozen for only 6 hours at −10° C, survival was much higher.

The *A. cristatum* checks showed continued high survival. Differences in seedling survival of the warm temperature species frozen for only 6 hours were not significant. It is interesting to note the low survival of *P. virgatum*. This is true in spite of the fact that seedlings of this species were more vigorous than those of any other species except *A. cristatum*.

In all cases seedlings of the various geographical strains showed striking differences in type and rate of growth. *B. gracilis* seedlings from North Dakota were much shorter than those from Nebraska and Texas, with tillers developing more rapidly. *A. furcatus* strains from Kansas and Texas were much more vigorous and rapid growing than the North Dakota strain. The Oklahoma *P. virgatum* grew much more rapidly and much taller, with fewer tillers than that from Nebraska and North Dakota.

Seedling survival of cool temperature species was much higher than that of warm temperature species when frozen artificially at the same age, temperature, and exposure. Seedlings of cool temperature species 35 and 63 days old were frozen at −18° C for 24 hours. Data presented in Table 3 show the results obtained with the 63-day seedlings. Survival obtained from the two age groups was similar in character. At this temperature cold injury was severe and mortality high. Variation in the ability of the various strains to survive was great and standard errors were high. It is evident, however, that *Agropyron cristatum* and *A. smithii* have greater cold resistance at this age than *Bromus inermis* as there was no survival of the latter species. The *A. cristatum* check showed no survival. This was due to the fact that the seedlings had become infected with root-rotting organisms before transplanting. Most of the seedlings died before freezing. The remaining few were so weakened that they could not withstand the low temperature. Other strains were not infected.

Since a temperature of −18° C for 24 hours was too severe to allow for survival of *B. inermis* and for much differentiation between *A. cristatum* and *A. smithii*, the temperature was raised and exposure shortened for the next freezing trial. Seedlings 72 and 44 days old were frozen at −10° C for 22 hours. Table 3 gives the survival results of this trial. Both age groups reacted similarly to this temperature and exposure. Here again the percentage survival of *B. inermis* was lower than that of the other two species. *A. smithii* from North Dakota gave a significantly higher survival than the Texas strain,

TABLE 3.—*Seedling survival of cool temperature species frozen at three ages, at two temperatures, and for three periods of time.*

| Accession No. | Species | Strain | Origin | Percentage survival | | | |
|---|---|---|---|---|---|---|---|
| | | | | Frozen at −18° C | Frozen at −10° C | | |
| | | | | 63-day seedlings frozen 24 hours* | 72-day seedlings frozen 22 hours† | 44-day seedlings‡ | |
| | | | | | | Frozen 22 hours | Frozen 12 hours |
| 952 | *A. cristatum* (check) | Standard | Mandan, N. Dak. | 0.00 | 83.32±12.9 | 97.80± 1.5 | 72.20± 7.0 |
| 13 | *A. smithii* | Bulk | Mandan, N. Dak. | 30.00±16.3 | 92.78± 4.9 | 89.26± 6.5 | 96.67± 3.4 |
| 449 | *A. smithii* | Bulk | Manhattan, Kans. | 11.67± 4.8 | 78.66±13.7 | 80.00± 5.9 | 96.67± 3.4 |
| 668 | *A. smithii* | Bulk | Temple, Tex. | 0.00 | 47.24±12.3 | 40.00±10.2 | 70.00± 8.3 |
| 750 | *B. inermis* | Parkland | Canada | 0.00 | 38.82± 9.1 | 38.89±14.5 | 60.00±15.6 |
| 1250 | *B. inermis* | Commercial | N. Dak. | 0.00 | 67.88± 6.9 | 46.67±14.8 | 53.33±14.8 |
| 1253 | *B. inermis* | Commercial | Kansas | 0.00 | 65.00±11.2 | 26.67±12.2 | 58.13±16.3 |
| 23 | *A. cristatum* | Fairway | Mandan, N. Dak. | 15.09± 9.3 | 100.00 | 96.67± 3.4 | 96.30± 3.8 |
| 96–24 | *A. cristatum* | Standard | Mandan, N. Dak. | 11.61± 5.4 | 93.46± 2.8 | 100.00 | 96.67± 3.4 |
| 1227 | *A. cristatum* | Standard | Nebraska | 12.70± 7.5 | 76.20±11.4 | 78.33±11.9 | 95.83± 4.2 |

*Average of six randomized replications.
†Average of five randomized replications.
‡Average of three randomized replications.

but the difference between the North Dakota and Kansas strains or the Kansas and Texas strains was not significant. When standard errors were calculated, including all strains as a group, within each species, it was found that *A. cristatum* survival was higher than that of *A. smithii* and *A. smithii* higher than that of *B. inermis*. When 44-day seedlings were frozen at –10° C for only 12 hours survival was higher than at longer exposures, but the same general relationship existed as to the survival of the various cool temperature species.

In considering the relation of height, vigor, and stage of development in relation to survival, it was found that *B. inermis* seedlings were taller, more vigorous, and further advanced in development than those of the other two species. Seedlings of the Parkland strain were slower growing, less vigorous, and shorter than North Dakota and Kansas *B. inermis*. *A. smithii* seedlings developed tillers more slowly than those of the other two species and there was little variation in strains. Fairway *A. cristatum* was finer leaved, shorter, and had a more rapid development of tillers than other strains of this species.

Two series of cool temperature species clones were frozen artificially. In one series they were hardened as usual and frozen at –21° C for 24 hours, thawed at 2° C for 48 hours, and again frozen at –10° C for 24 hours. The other series was frozen at –20° to –23° C for 24 hours. In both trials the temperature and exposure were too extreme and survival was low. A few new shoots started from at least one plant of each strain of *A. cristatum*, but none from any plants of the other two species. These new shoots soon died, however. The fact that *A. cristatum* plants started to make growth suggests that this species may be more resistant to extreme cold and exposure in the clonal stage than *A. smithii* and *B. inermis*. It is believed that greater survival would have been secured if a hardening period of more than 7 days at 2° C had been used.

Clones of the warm temperature species were also frozen at various temperatures and exposures. Since these species tend to become dormant in the fall regardless of temperature, the data obtained were not considered reliable. Experience in handling these species indicates that artificial freezing studies with warm temperature species could best be carried on in the spring after growth had started but before seed stalks are produced.

Observational notes were obtained on the speed at which the leaves of the various species were frozen after being placed in the freezing chamber. Almost without exception, leaves of both seedlings and clones of cool temperature species were frozen more rapidly than those of the warm temperature species. This may have been caused by a higher water content of the leaves of the cool temperature species. In many cases the leaves of the latter species, even though frozen stiff, would thaw out and not be injured. The warm temperature species froze more slowly, but if frozen, lacked the ability to revive after thawing. Freezing injury to young leaves was generally more severe than to more mature tissue. The first injury occurs at the tips of the leaves. More severe treatment often caused complete killing; or if new growth was produced, it came from the crown of the plant or from rhizomes.

## DISCUSSION

A true inherited difference is apparent in northern and southern strains of warm temperature species of grasses as to their ability to survive cold temperatures. This fact is indicated in both the seedling and mature plant stage. The widely separated geographical strains of warm temperature species studied most certainly show a different physiological response throughout their life history to photoperiod and climate when grown at Mandan, N. Dak. Southern strains seem to have less ability to harden off either as seedlings or mature plants. Seedlings of warm temperature species from southern regions are more susceptible to freezing injury than seedlings of these species from northern regions, and much less capable of withstanding low temperatures than seedlings of cool temperature species.

In the mature plant stage southern strains of warm temperature species are so late in maturity that fall frosts catch them before maturity and before starting to become dormant while they are still in a more or less vigorous growing condition. Northern strains have at least started to become dormant before the first freeze. It appears that the warm temperature species must be relatively dormant when the first freeze comes to show high survival.

Both northern and southern strains of cool temperature species mature early in the summer and do not show the marked difference in growth type and vigor as related to origin. Even though these species are growing vigorously, as they often are in the fall, no cases of winterkilling have occurred. It is the inherent character of these species to be more hardy than the warm temperature species. The data on seedling survival are interesting in that the Texas strain of *A. smithii* did not survive artificial freezing as well as did more northern strains. Field results have not borne this out. In the case of *B. inermis* the Kansas strain did not differ from the North Dakota strain. There was also little difference in *A. cristatum* strains of different origin as to seedling survival.

In the case of the latter two species differences would be less likely to occur since they are introduced species. Natural selection has probably not had time to bring out the marked differences in various geographical strains as are found in the native species.

## SUMMARY

The purpose of this study was to obtain information on the resistance to low temperature of seedlings and mature plants of geographical strains of grasses.

*Agropyron cristatum*, *A. smithii*, and *Bromus inermis* are classified as cool temperature species because they make their maximum vegetative growth in the cool period of the growing season. *Bouteloua gracilis*, *B. curtipendula*, *Andropogon furcatus*, and *Panicum virgatum* are classified as warm temperature species because they make their maximum vegetative growth during the warmest period of the growing season.

Strains of the warm temperature species from the same general geographic origin react similarly to the winter climate at Mandan,

N. Dak. The average field survival of these species decreases as their origin becomes more southerly. There has been no injury to the cool temperature species in the field regardless of origin.

There is a definite tendency for seedlings of warm temperature species of northern origin to survive in greater proportion after artificial freezing than those of more southern origin. With cool temperature species the only significant differences were obtained with *A. smithii*. Seedlings of this species from the south were less resistant to cold temperatures than those from the north.

Under all treatments the *A. cristatum* seedlings gave higher survival than those of *A. smithii* and seedlings of *A. smithii* gave higher survival than those of *B. inermis*.

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# EFFECT OF FERTILIZATION OF A CROWLEY CLAY LOAM ON THE CHEMICAL COMPOSITION OF FORAGE AND CARPET GRASS, *AXONOPUS AFFINIS*[1]

G. S. FRAPS, J. F. FUDGE, AND E. B. REYNOLDS[2]

THE value of commercial fertilizers for pastures has been the subject of considerable research in recent years. The chemical composition is particularly of value in areas where, as in Texas and particularly along the Gulf Coast, quality rather than quantity of forage is often the limiting factor in animal production. Some workers (1, 2, 3, 10, 11, 12)[3] have studied the effect of fertilizers on the chemical composition of single species of pasture plants, but most of the work has been done on changes in botanical composition of the pastures and in chemical composition of the mixed herbage. This paper presents a study of variations in yield and protein, phosphoric acid, and lime in total forage and carpet grass, *Axonopus affinis*, caused by fertilization of a Crowley clay loam soil.

## PLAN OF THE EXPERIMENT

Crowley clay loam is a soil type of considerable importance on the Gulf Coast Prairie of Texas. The particular area used was located at Substation No. 4 at Beaumont. Plots were 14 feet by 4 feet 7 inches. Forage consisted principally of carpet grass with small amounts of Dallis grass, *Paspalum dilatatum*, lespedeza, *Lespedeza striata*, white clover, *Trifolium repens*, and black medic, *Medicago lupulina*. Six different fertilizer treatments were made as follows: O, none; N, nitrate of soda, 80 pounds per acre; A, sulfate of ammonia, 100 pounds per acre; P, superphosphate, 20%, 160 pounds per acre; AP, combination of A and P; APK, combination of A and P, plus 32 pounds per acre of muriate of potash.

A second series of six plats received the same fertilizers plus lime (L) at the rate of 1 ton per acre. Fertilizers were applied about the middle of January of each year from 1935 through 1939. Lime was applied in 1935, 1937, and 1939. This series of treatments was replicated four times.

Samples of soil at two depths, 0 to 6 inches and 6 to 12 inches, were secured from the 48 plots. Samples from the four plots receiving the same treatment were composited and analyzed for total nitrogen, active (0.2 N nitric acid-soluble) phosphoric acid, and pH. Potash was not determined, but the soils were probably well supplied with that constituent (5).

Forage was mowed with a lawn mower each month of the growing season (March through September) and in December, 1938, and November, 1939. A part of the clippings was taken for fresh and air-dry weights. Samples of carpet grass were separated from the dry samples. The samples of carpet grass (or of the remaining forage) from the four plots receiving the same treatment were then combined, ground in a Wiley mill, and analyzed for protein, phosphoric acid, and

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[3]Figures in parenthesis refer to "Literature Cited", p. 565.

lime. From the weights and analyses of the carpet grass and of the residual forage, the analysis of the original total forage was calculated. Data for 180 yields and percentages of protein, phosphoric acid, and lime in 180 samples each of total forage and carpet grass were secured. This large volume of data is not presented in detail because of the limitations of space. Average yield and composition for the fertilizer treatments are given in Table 1; those based on dates of clipping are given in Table 2.

## EXPERIMENTAL RESULTS

### THE SOILS

Nitrogen in the surface soils averaged 0.131% on the unlimed plots and 0.121% on the limed plots, and in the subsoils, 0.108% and 0.098% respectively. The limed plots were slightly, but not significantly, lower in total nitrogen. The pH values of the same soils averaged 5.8, 6.6, 5.9, and 6.2, respectively. Some downward movement of the lime is apparent.

Active phosphoric acid was low in all of the soils. Averages for the four groups of plots were for (a) no phosphate and no lime, (b) phosphate and no lime, (c) no phosphate but limed, and (d) both phosphate and lime, 22, 23, 24, and 32 p.p.m. in the surface soil and 17, 18, 23, and 20 p.p.m. in the subsoil, respectively. At the time the soil samples were collected (January, 1938), the superphosphate added contained the equivalent of a total of 96 pounds of phosphoric acid per acre. Very little of this appears in an increase in active phosphoric acid in the soil. Phosphoric acid in the forage accounts for only a small part of the total added. Evidently, most of the phosphoric acid added was combined in compounds which were insoluble in 0.2 N nitric acid. Lime with the superphosphate considerably reduced the formation of these compounds, but the increase in active phosphoric acid in these plots accounts for only about 20% of the total added. The lack of significant increase in active phosphoric acid in the unlimed plots of this soil is in agreement with results reported for a similar soil (Lake Charles clay loam) at Angleton in which active phosphoric acid showed no significant increase except with very high applications of superphosphate (8).

### EFFECT OF FERTILIZERS ON YIELDS OF FORAGE

Nitrate of soda significantly increased the yields of forage over the 2-year period. The increase in yield from the limed plots (22%) was slightly greater than that from the unlimed plots (16%) and considerably greater in 1939 (25%) than in 1938 (16%). Sulfate of ammonia did not produce a significant increase on the unlimed plots (5%) but did on the limed plots (17%). Muriate of potash did not significantly increase the yield from any group of plots.

Superphosphate more than doubled the yields on the unlimed plots (increases of 105% in 1938 and 106% in 1939) and greatly increased those from the limed plots (75% in 1938 and 54% in 1939). Superphosphate greatly increased the growth of lespedeza which formed an important part of the forage only on plats which had received superphosphate. This indicates that the growth of legumes may be

TABLE 1.—*Total yields and average chemical composition of forage and carpet grass receiving different fertilizer treatments.*

| Treatment | Total yield of dry matter, lbs. per acre | | Protein, % | | | | Phosphoric acid, % | | | | Lime, % | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Total forage | | Carpet grass | | Total forage | | Carpet grass | | Total forage | | Carpet grass | |
| | 1938 | 1939 | 1938 | 1939 | 1938 | 1939 | 1938 | 1939 | 1938 | 1939 | 1938 | 1939 | 1938 | 1939 |
| O | 2,495 | 1,629 | 8.20 | 8.25 | 6.77 | 7.19 | 0.26 | 0.27 | 0.23 | 0.24 | 0.91 | 0.81 | 0.74 | 0.69 |
| N | 2,864 | 1,922 | 8.07 | 8.13 | 6.88 | 7.31 | 0.26 | 0.25 | 0.24 | 0.25 | 0.77 | 0.73 | 0.71 | 0.64 |
| A | 2,708 | 1,943 | 8.10 | 8.47 | 6.99 | 7.25 | 0.27 | 0.29 | 0.24 | 0.25 | 0.80 | 0.76 | 0.69 | 0.64 |
| P | 5,394 | 3,746 | 10.56 | 10.31 | 7.59 | 7.84 | 0.41 | 0.40 | 0.34 | 0.36 | 1.06 | 0.95 | 0.69 | 0.71 |
| AP | 5,601 | 3,659 | 9.79 | 9.80 | 7.61 | 7.61 | 0.40 | 0.39 | 0.35 | 0.37 | 1.00 | 0.85 | 0.71 | 0.69 |
| APK | 5,510 | 4,272 | 9.94 | 10.44 | 7.88 | 8.15 | 0.41 | 0.42 | 0.37 | 0.38 | 1.09 | 0.99 | 0.77 | 0.74 |
| L | 3,630 | 2,500 | 8.87 | 8.78 | 7.43 | 7.49 | 0.29 | 0.27 | 0.25 | 0.27 | 1.00 | 1.03 | 0.84 | 0.86 |
| NL | 4,251 | 3,237 | 8.76 | 8.80 | 7.81 | 7.81 | 0.28 | 0.30 | 0.25 | 0.27 | 0.90 | 0.95 | 0.74 | 0.83 |
| AL | 3,812 | 2,463 | 8.56 | 8.56 | 7.60 | 7.68 | 0.27 | 0.30 | 0.25 | 0.27 | 1.00 | 0.97 | 0.81 | 0.81 |
| PL | 5,703 | 4,017 | 11.06 | 10.79 | 8.61 | 8.59 | 0.46 | 0.42 | 0.39 | 0.39 | 1.26 | 1.16 | 0.84 | 0.90 |
| APL | 7,011 | 4,296 | 10.44 | 9.85 | 8.67 | 8.37 | 0.46 | 0.41 | 0.40 | 0.39 | 1.24 | 1.09 | 0.94 | 0.91 |
| APKL | 7,380 | 4,464 | 10.44 | 10.76 | 8.40 | 8.36 | 0.41 | 0.38 | 0.37 | 0.34 | 1.29 | 1.15 | 0.94 | 0.93 |

TABLE 2.—*Total yields and average chemical composition of forage and carpet grass clipped at different dates.*

| Month | Total yield of dry matter, lbs. per acre | | Rain between cuttings, in. | | Protein, % | | | | Phosphoric acid, % | | | | Lime, % | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Total forage | | Carpet grass | | Total forage | | Carpet grass | | Total forage | | Carpet grass | |
| | 1938 | 1939 | 1938 | 1939 | 1938 | 1939 | 1938 | 1939 | 1938 | 1939 | 1938 | 1939 | 1938 | 1939 | 1938 | 1939 |
| Mar | 507 | 100 | 1.44 | 0.72 | 13.37 | 12.32 | 11.00 | 10.56 | 0.50 | 0.39 | 0.44 | 0.38 | 1.59 | 1.55 | 1.04 | 1.19 |
| Apr | — | 100 | — | 0.79 | — | 11.13 | — | 8.79 | — | 0.36 | — | 0.32 | — | 1.29 | — | 0.92 |
| May | 386 | 538 | 9.22 | 3.52 | 9.53 | 8.69 | 8.88 | 7.90 | 0.34 | 0.34 | 0.33 | 0.32 | 1.12 | 0.83 | 0.96 | 0.73 |
| June | 860 | 178 | 5.52 | 1.64 | 8.78 | 7.67 | 7.63 | 7.50 | 0.34 | 0.30 | 0.32 | 0.31 | 1.00 | 0.78 | 0.79 | 0.73 |
| July | 1,117 | 1,095 | 2.84 | 4.55 | 7.04 | 7.98 | 6.13 | 7.18 | 0.38 | 0.38 | 0.31 | 0.35 | 0.73 | 0.65 | 0.62 | 0.56 |
| Aug | 1,216 | 579 | 7.27 | 2.95 | 9.40 | 9.94 | 6.62 | 7.88 | 0.35 | 0.35 | 0.29 | 0.32 | 1.07 | 0.83 | 0.75 | 0.62 |
| Sept | 526 | 518 | 4.77 | 2.25 | 10.19 | 9.35 | 7.85 | 6.09 | 0.34 | 0.33 | 0.31 | 0.33 | 1.03 | 0.85 | 0.70 | 0.74 |
| Nov | — | 70 | — | 4.71 | — | 10.32 | — | 6.73 | — | 0.31 | — | 0.27 | — | 0.85 | — | 0.70 |
| Dec | 102 | — | 7.76 | — | 6.65 | — | 5.58 | — | 0.18 | — | 0.16 | — | 0.75 | — | 0.65 | — |

conditioned largely by the supply of available phosphoric acid in the soil.

Lime increased yields by averages of 31% in 1938 and 22% in 1939. It increased the relative effect of nitrate of soda and sulfate of ammonia and decreased that of superphosphate. The latter fact indicates that liming increased the availability of the phosphoric acid already present in the soil. This indication is supported by the fact that active phosphoric acid was slightly higher in the limed soils than in the unlimed soils.

## EFFECT OF FERTILIZERS ON CHEMICAL COMPOSITION

Nitrate of soda had no significant effect on the protein or phosphoric acid in either forage or carpet grass and caused slight but insignificant decreases in lime. Sulfate of ammonia had no effect upon the chemical composition of either forage or carpet grass. Results with nitrogenous fertilizers are different from those secured in most of the experiments reviewed by Vandecaveye (13), who concluded that, "applications of nitrogenous fertilizers for pasture grass and hay can be expected to affect increased percentages of nitrogen in the herbage." The difference in results may be due in part to difference in the species studied (14).

Potash had no significant effect on the chemical composition of forage or carpet grass. This was to be expected since the soil probably already contained sufficient potash for excellent growth (5).

Superphosphate caused increases of 29% in protein, 54% in phosphoric acid, and 26% in lime in total forage from the unlimed plots, while from the limed plots the corresponding increases were 28%, 48%, and 20%. Corresponding increases in carpet grass were 10%, 50%, and 6% on the unlimed plots and 12%, 46%, and 11% on the limed plots. The increase in lime content of the forage due to the application of superphosphate was as great as the increase due to liming. The difference in lime content of forage from plots which had received superphosphate but no lime and from those which had received lime but no superphosphate was not significant. The increase in lime content of carpet grass was not as large as that in forage but was still slightly significant. The results secured for superphosphate are in general accord with those secured by other workers (1, 2, 3, 10, 12, 14).

Superphosphate greatly reduced the number of samples which contained less than 0.33% phosphoric acid and less than 6.00% protein and were therefore probably deficient in phosphoric acid and protein for animal production (7). Assuming that 0.32% $P_2O_5$ is the critical point, phosphoric acid was not deficient in 171 samples. Phosphoric acid was deficient in 189 samples of which 163 were from plots which had not received superphosphate. Nineteen of the 26 samples from phosphated plots which were deficient in phosphoric acid were collected in November and December when growth had practically stopped. The date at which samples from the phosphated plats became deficient in phosphoric acid depended to some extent upon the weather. In 1938, a deficiency of $P_2O_5$ in the forage did not occur until December; but in 1939, with much less favorable

rainfall, a deficiency was observed in samples of carpet grass collected in September and most of the samples collected in November were deficient. Protein was deficient in only 18 of the 360 samples, of which 14 were from plots which had not received superphosphate and 12 from unlimed plots.

Lime increased the protein content of total forage by 5% and of carpet grass by 9%, the phosphoric acid content of forage by 7%, and of carpet grass by 9%, and lime content of both forage and carpet grass by 22%.

## VARIATIONS WITH DATES

Variations in yield and chemical composition were much greater at different periods of growth than with different fertilizer treatments, as may be seen by comparing the data in Tables 1 and 2. The greatest variation in connection with dates was in the yields for 1938 and 1939. This was probably due to a difference in rainfall in the two years. The total yield in 1938 was 48% higher than in 1939. Total rainfall during the growing season in 1938 (38.82 inches) was 82% higher than in 1939 (21.33 inches). The rainfall in 1938 was distributed much better, no month having a marked deficiency, while March, April, and June of 1939 were deficient as shown by very low yields as compared with the same months in 1938. However, the difference in rainfall did not cause significant differences in average percentages of protein, phosphoric acid, or lime in either forage or carpet grass. The only appreciable difference between the two years was in the earlier appearance of samples deficient in phosphoric acid in the fall of 1939 as compared with 1938. The difference in chemical composition caused by the difference in rainfall was not nearly as marked as in the results reported for alfalfa and little bluestem in Oklahoma (4) in which an increase in rainfall decreased lime and increased phosphoric acid.

Variations in chemical composition at different dates through the year were not as large as those in yield, but the data show definite trends. Protein showed a general downward trend until July, after which it increased until late in the fall. When considered on a bimonthly basis the changes were highly significant. Phosphoric acid was high in samples of forage and carpet grass collected in March, low in those collected in December, 1938, and fairly uniform throughout the rest of the year. Lime decreased from March through July, after which there was a slight upward trend.

Forage was higher than carpet grass in protein, phosphoric acid, and lime, but the ratios between the two varied considerably with different dates and fertilizer treatments. The increase in protein due to liming was considerably greater for carpet grass than for forage, while that due to superphosphate was considerably greater for forage than for carpet grass. The increases in protein and phosphoric acid due to superphosphate were much greater in total forage than in carpet grass in March as compared with July, and on unlimed as compared with limed plots. Because most of the samples represented young material grown during the preceding month, there was not very much difference in chemical composition of

samples taken at intervals during the season (Table 2). However, mature samples collected in January and December, 1938, were relatively low in phosphoric acid and protein and did not vary significantly with different fertilizer treatments. Thus, although marked differences in the chemical composition of young plants occurred with different treatments (Table 1), these variations decreased as the plants approached maturity and protein and phosphoric acid dropped to low levels. This agrees with results already reported (4, 5, 7) for other forage in Texas.

## SUMMARY

Protein, phosphoric acid, and lime were determined in total forage and carpet grass clipped at monthly intervals through two growing seasons in 1938 and 1939 from plots of a Crowley clay loam at Beaumont, Texas, which had received six different fertilizer treatments with and without lime. Unfertilized carpet grass and forage were often deficient in phosphoric acid, less frequently in protein, and not at all in lime.

Sodium nitrate produced a significant increase in yield but did not affect the chemical composition of total forage or carpet grass. Ammonium sulfate alone increased the yield of forage to some extent but had little effect on chemical composition. Muriate of potash had no effect upon either the yield or chemical composition.

Superphosphate greatly increased the yield and the protein, phosphoric acid, and lime content of total forage and of carpet grass. It decreased the number of samples which were deficient in phosphoric acid for animal production.

Lime alone increased yield of forage 45 to 53%. It also increased the protein, phosphoric acid, and lime in the total forage and in carpet grass.

Variations in yield and chemical composition were much greater with different dates than with different fertilizer treatments. Protein and lime decreased from early spring until July and increased from then until late fall. Phosphoric acid was high in the early spring samples and then fairly constant throughout the remainder of the growing season. Rainfall in 1939 was sufficiently lower than that in 1938 to cause a large reduction in yield, but the difference in rainfall did not significantly affect the chemical composition of forage or carpet grass.

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# EFFECT OF SURFACE STONES ON EROSION, EVAPORATION, SOIL TEMPERATURE, AND SOIL MOISTURE[1]

J. LAMB, JR., AND J. E. CHAPMAN[2]

SURFACE stones on cultivated lands are usually regarded as a nuisance, and are often removed at considerable expense. Examination of clean-cultivated sloping fields after heavy rains shows that the flat stones form miniature soil-saving dams and terraces. The stones break the fall of the rain drops, and it has been suggested that they also might act as a mulch and decrease surface evaporation. Areas under the larger stones frequently show worm and insect action, with the soil moist and granular, and, probably, absorptive.

Stones are common on farm lands and frequently present a serious agricultural problem. Thus, information in regard to their action on soil and water conservation is of value and should help in directing cultural practices.

There is little mention of this problem in soil literature. Buck (1)[3] states that the Chinese use several inches of gravel as a mulch for annual grain crops, removing the stones each year before seeding. Brailowsky[4] reports that flat stones have been used with success to conserve moisture and prevent weed growth in a vineyard at Montpellier, France.

Duley and associates (2, 3) and many others have found that crop residues and plant mulches reduce runoff and evaporation thus increasing the moisture content of the soil and crop growth.

Evaporation studies have been numerous. In 1888, Russell (6) and, in 1894, King (5) used the Piche evaporimeter to determine the evaporation from a free water surface and from soils. Wilson (8) used the Livingston atmometer in his 10-year study of evaporation conditions in Ohio. A modification of this principle, the humidity gradient, was used by Thornthwaite and Holzman (7). All these studies of atmospheric moisture conditions show evaporation to be an important cause of moisture loss from soil. However, where direct weighing methods have been used to measure evaporation, as reviewed by Harris and Robinson (4), there has been some conflict in opinions as to the importance of such loss of water from soil.

The studies that follow were made at the Arnot Soil Conservation Experiment Station operated by the U. S. Dept. of Agriculture and the Cornell University Experiment Station. The Station is located at the University Arnot forest 17 miles southwest of Ithaca, N. Y., at an elevation of 1,200 to 1,900 feet.

[1]Contribution from the Division of Research, Soil Conservation Service, U. S. Dept. of Agriculture, in cooperation with the Cornell Agricultural Experiment Station. Received for publication January 15, 1943.

[2]Project Supervisor and Junior Soil Technologist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 578.

[4]Information supplied by A. Brailowsky, former Special Assistant in Research, New York State Agricultural Experiment Station, Geneva, N. Y., by letter December, 1941.

## METHODS

There were three types of plots used, namely, large field plots, small field plots, and small weighed boxes. Erosion and soil temperatures were determined with 1/100-acre field plots, 6 feet wide and 72.6 feet long. Small field plots, 5 by 5 feet were used to study the effect of surface stones on soil moisture. Evaporation, percolation, and additional runoff data were obtained by direct weighing of soil boxes 36 inches long, 16 inches wide, and 9 inches deep, which held an 8-inch depth of soil.

Evaporation rates from a free water surface were measured by means of a class A evaporation pan, and a 10-inch pan supported by a recording rain gage gave continuous rates. Three to four standard rain gages were used to measure the rainfall. Soil temperatures were secured by means of copper-constantan thermocouples and a potentiometer calibrated in degrees Fahrenheit. Soil moisture conditions were determined by tensiometers.

The field plots, small plots, and all equipment were located within a radius of 150-feet, on an 18 to 20% southeast slope. The soil series was the Bath flaggy silt loam, with about 18% of the normal cultivated surface covered with flat sandstone fragments ranging from 1-inch to flagstone size.

The A series field runoff plots had been completed in April 1935. They were surrounded by steel border plates that projected 6 inches above the soil surface and penetrated to a depth of 12 inches below, and water and soil were collected in covered tanks at their base. These plots were spaded to plow depth once each season, late fall or early spring, and the stones mixed through the entire plow layer. All the fallow plots were cultivated at the same time the corn was cultivated. The shallow summer cultivation tended to work the stones to the surface, and two to three times a year stones above 2 inches in largest dimension were removed from plot A-7 and weighed. No stones were removed from plots A-5 or A-8. The B series field runoff plots were established from an old sod of mixed clover and grass July 1939. Plot B-15 was mulched with oat straw at the rate of 6-tons per acre. Plot B-16 was clean cultivated with no crop.

Five small field plots, 5×5 feet, were spaded to plow depth from an old sod of mixed clover and grass during August 1941. The plant stems and roots were removed from the plots at the time. The treatments were as follows: Stones removed above 2-inches largest dimension; natural stone cover on approximately 18% of surface; stones added to give approximately 65% stone cover; stones added to give 4-inch layer of stones, 100% stone cover; stones added to give 8-inch layer of stones, 100% stone cover.

Soil water tensions in these plots were secured at depths of 3, 10, and 20 inches. After September 15, the stones were removed and water sprinkled on the plots as needed until the tensions of the soil water of all the plots approached the same level. The stones were then replaced, but not on the same plots, as indicated later in Table 5.

The direct weighing soil boxes were placed in a shallow pit so that the surface of the soil in the boxes would be on the same plane as the adjoining field soil, and all apertures between and about the boxes were covered to reduce air movement. The boxes were weighed with steelyards to an accuracy of 0.2 pound, equivalent to 0.01 inch of water. A double bottom allowed free percolation. In the summer of 1938, eight soil boxes were each filled with well-mixed dry surface soil consisting of 186.2 pounds (oven-dry basis) of material which passed through a ¼-inch screen, and 63.5 pounds of stones that did not pass through the same screen. This

ratio of stones to fine material represented field conditions. In six boxes, the flag stones were mixed through the mass of the soil. In two boxes, stones with the long dimension of 2 inches or more, which amounted to 17 pounds per box, were placed on top of the soil to cover approximately 65% of the surface.

Few stones exceeded 6 inches in the long dimension. The boxes to receive treatments were selected at random. The character of the surface cover and the treatments are indicated in Fig. 1. Each spring the fallow soil was cultivated about 6 inches deep, with the surface stones on the soil of the 65% stone treatments removed before and replaced after the process. The soil of two of the 18% stone cover boxes was held in a freshly cultivated condition during the season of 1940. Weeds were removed as soon as they appeared in all treatments. Oat straw with which two other boxes were covered at the rate of 6 tons per acre was held in place by 1-inch mesh poultry netting. All boxes, covered in the winter but not insulated to any extent, were exposed to freezing temperatures. It was assumed that after correcting for rainfall, percolation, and runoff, the losses in weight of the soil boxes from day to day were due to loss of water by evaporation. No attempt was made to measure the amount of vapor condensation.

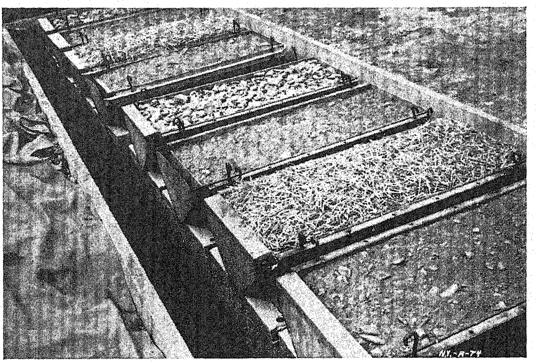

FIG. 1.—Soil weighing boxes partly stripped to show construction details. Cover treatments from left to right are 67% stone, 18% stone, oat straw, 18% stone, 67% stone, 18% stone, oat straw, and 18% stone.

## EXPERIMENTAL RESULTS

### EFFECT OF SURFACE STONES ON EROSION FROM FIELD PLOTS

The water and soil losses from the series A field plots A-5 and 8, stones in place, and plot A-7, stones removed, are indicated in Table 1. Plots A-7 and A-8 are shown in Fig. 2. Removal of the large stones almost doubled the water loss and in 1940 increased the soil loss more than six times. The soil loss has all been due to sheet erosion, and the loss of some of the finer portion of the soil seems to decrease

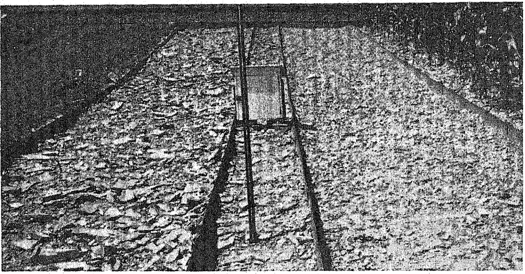

FIG. 2.—Arnot fallow plots A-7 surface stones about 2 inches removed, A-8 surface stones in place. The metal tubes in the soil are parts of tensiometers.

gradually the severity of the erosion. About 40% of this soil, while in place in the fields and where no stones have been removed will pass through a ¼-inch screen, but about 97% of the eroded material will pass through the same screen. Few of the stones that do not pass through are larger than ½ inch in long dimension.

TABLE 1.—*Effect of surface stones on soil and water loss from series A field plots.*

| Year* | Rain-fall, inches | Stones in place, fallow, plot A-8 | | Stones removed, corn 1935–36–37; fallow 1938–39-40, plot A-7 | | Stones in place, corn, plot A-5 | |
|---|---|---|---|---|---|---|---|
| | | Water loss, % | Soil loss per acre, lbs. | Water loss, % | Soil loss per acre, lbs. | Water loss, % | Soil loss per acre, lbs. |
| 1935........ | 22.7 | 15.0 | 17,127 | 13.8 | 16,150 | 8.2 | 8,520 |
| 1936........ | 20.4 | 13.2 | 30,179 | 8.7 | 17,495 | 4.8 | 8,546 |
| 1937........ | 31.3 | 20.1 | 26,973 | 18.8 | 18,886 | 10.2 | 6,522 |
| Av. for 3 yrs. | 24.8 | 16.1 | 24,760 | 13.8 | 17,510 | 7.7 | 7,863 |
| 1938........ | 20.9 | 18.1 | 14,646 | 23.6 | 22,491 | 9.0 | 4,446 |
| 1939........ | 16.8 | 15.4 | 8,212 | 25.0 | 24,746 | 15.0 | 9,782 |
| 1940........ | 23.0 | 8.2 | 5,496 | 19.6 | 32,730 | 5.0 | 3,433 |
| Av. for 3 yrs. | 20.2 | 13.9 | 9,451 | 22.7 | 26,656 | 9.7 | 5,887 |

*Period May through October.

## EFFECT OF SURFACE STONES AND STRAW MULCH ON EVAPORATION FROM SOIL IN WEIGHED BOXES

The summer evaporation in central New York is appreciable, and a lack of soil moisture during the growing season frequently causes

reduced crop yields and crop failures. The introduction of commercial overhead irrigation systems, in some cases for crops like potatoes, is evidence of recognition of this condition.

The actual amount of water in each soil box on each weighing date in 1938 is presented in Fig. 3, expressed both as inches and as percentage of moisture in the soil. The percentage is based on the

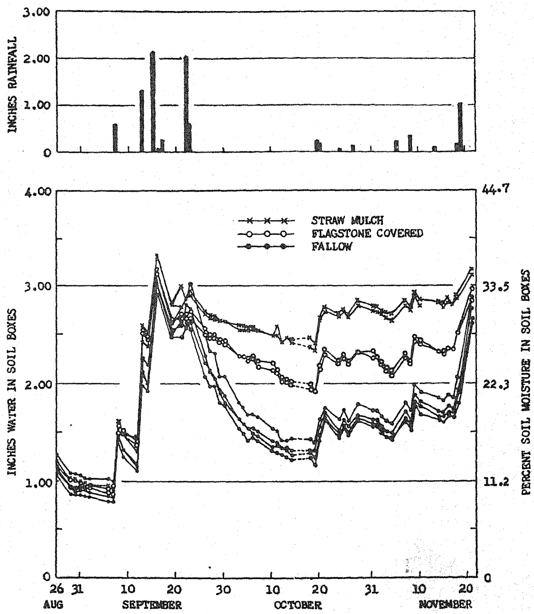


FIG. 3.—Influence of surface stones and straw mulch on water content of soil in individual weighing boxes, 1938.

dry weight of the material that passed through a ¼ inch screen. The initial moisture was about 12%. Before the first rain there was little evaporation and only slight differences in the amount lost from the variously treated soils. After there was sufficient rain to wet the soil, the treatments showed consistent differences and the weight losses from the replicates showed reasonably good agreement. At no time in 1938, after the soil was once wet, did the soil

under the straw mulch become as dry as the soil of either of the other treatments.

During a period of low rainfall, May 12 to July 20, 1939, not shown in Fig. 3, the straw-mulched soil reached practically the same moisture level as the soil under the 65% stone cover and 18% stone cover.

The data for 1940 are not unlike those of the previous years and are illustrated in Fig. 4. The frequent cultivation of the soil in boxes 3 and 7 caused the soil to hold more water for the period, decreased the runoff from 44 to 23% of the rainfall, but increased the evaporation from 50 to 77%.

During periods in 1939 and 1940 when the weights of soil boxes were obtained at frequent periods, the stones seemed to increase the

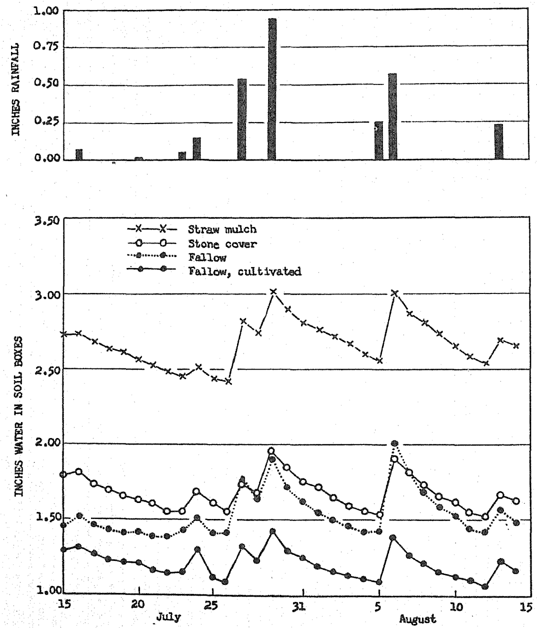


FIG. 4.—Influence of surface stones, straw mulch, and cultivation on water content of soil in weighing boxes, 1940.

percolation and decrease the evaporation slightly. The straw mulch decreased runoff and evaporation and increased percolation.

The maximum loss in weight by evaporation in any 24-hour period was 0.15 inch of water. As much as 0.77 inch of water has been lost between rainstorms. The rain of August 4, 1939, thoroughly wetted the soil of all the boxes, and during the next 4 days the total loss in weight attributed to evaporation from the clean-cultivated, no-crop soil was equivalent to 0.60-inch of water.

The average evaporation from the replicates and from a free water surface is shown graphically in Fig. 5. The rate of soil moisture loss was comparatively high from the soil of all boxes regardless of treatment the first few days, but less from the straw-mulched soil. During this period, the evaporation from the soil increased or decreased much the same as that from the free water surface. After 9 days, the evaporation rate from the soil was essentially the same from all treatments and on August 17 it was slightly higher in the case of the straw mulch and 65% flagstone cover. At this time there was more water present under the straw mulch and stone cover, the vapor pressure near the surface was probably higher than in the case of the drier soils, and this greater vapor pressure gradient with the atmosphere caused the higher evaporation.

It is probable that immediately following a rain the soil in the boxes had a higher moisture content and a higher evaporation rate than field soils. This could be true because of a perched water table resulting from a truncated soil section. In a dry period it may have had a lower water content than a field soil since there was no opportunity for upward movement of moisture from the sub-soil.

## WATER-HOLDING CAPACITY OF SOIL UNDER STONES AND STRAW MULCH IN WEIGHED BOXES

The water content of the soil boxes following rains that caused considerable percolation should be near the maximum field capacity of the soil to hold water. During dry periods, small cracks appeared in the soil surface, but none seemed deep enough to influence percolation to an appreciable extent. The soils under the 65% stone cover and under straw have maintained more of the water-holding capacity of the original soil before packing than the soil with the lower percentage of stone cover (Table 2). The higher moisture content would indicate a physical condition that favored the retention of moisture.

TABLE 2.—*Percentage of water in soil of weighed boxes following rains that caused percolation.**

| Date of rains | 16–18% stones | 65% stones | Straw mulch |
|---|---|---|---|
| Sept. 23, 1938 | 35.5 | 35.1 | 37.9 |
| Sept. 30, 1939 | 22.1 | 27.3 | 30.0 |
| Aug. 6, 1940 | 21.9 | 25.0 | 31.5 |
| June 5, 1941 | 24.7 | 28.3 | 31.4 |

*Boxes weighed before appreciable evaporation occurred.

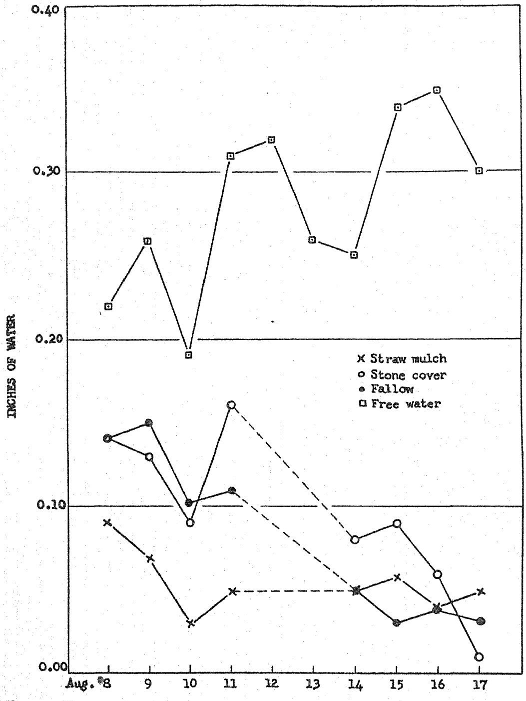


FIG. 5.—Evaporation from a free water surface and from the soil in weighing boxes after the rain of August 8, 1939.

## COMPARISON OF RUNOFF AND SOIL LOSSES FROM SOIL BOXES WITH THOSE FROM FIELD PLOTS

The runoff from the soil boxes is higher on the average than that from field plots (series B) with comparable slope and treatment. The data in Table 3 are representative of the results from rains where runoff occurred. The soil loss was greater from the soil boxes than the field soils in the case of three rains and less for one rain.

TABLE 3.—*Runoff and soil losses from soil in weighed boxes and on series B field plots from four rains in 1939.*

| Date of rains | Rainfall, inches | Soil boxes | | | Field plots | |
|---|---|---|---|---|---|---|
| | | Stones 18% cover | Straw mulch | Stones 65% cover | B-16, stones 18% cover | B-15, straw mulch |
| | | **Runoff % of Rainfall** | | | | |
| Sept. 21, 1939.. | 0.45 | 70.7 | 2.0 | 41.3 | 16.6 | 0.9 |
| Sept. 26, 1939.. | 1.39 | 51.7 | 1.2 | 42.2 | 17.1 | 0.7 |
| Sept. 27, 1939.. | 0.96 | 63.8 | 1.4 | 42.7 | 8.1 | 0.6 |
| Oct. 6, 1939.... | 0.37 | 68.6 | 2.2 | 54.6 | 46.6 | 0.5 |
| | | **Soil Losses, Lbs. per Acre** | | | | |
| Sept. 21, 1939.. | 0.45 | 765 | 0 | 192 | 738 | 0 |
| Sept. 26, 1939.. | 1.39 | 244 | 0 | 64 | 149 | 0 |
| Sept. 27, 1939.. | 0.96 | 601 | 0 | 37 | 154 | 0 |
| Oct. 6, 1939.... | 0.37 | 592 | 0 | 108 | 821 | Trace |

TABLE 4.—*Temperatures of field soils under fallow, 65% flagstone cover, and straw mulch.*

| Hours of sunlight | Mean air temperature, °F | Soil depth, in. | Temperature reading 9 a.m., °F | | | Temperature reading 2 p.m., °F | | |
|---|---|---|---|---|---|---|---|---|
| | | | Fallow | Stones* | Straw† | Fallow | Stones | Straw |
| | | | **Sept. 13, 1939** | | | | | |
| 7.6 | 50° | 0 | — | 72.5° | 56.5° | — | 88.0° | 69.0° |
| 7.6 | 50° | 1 | 62.5° | 65.0° | 57.5° | 80.0° | 83.0° | 66.0° |
| 7.6 | 50° | 3 | 58.0° | 60.0° | 57.0° | 74.0° | 72.5° | 64.0° |
| 7.6 | 50° | 10 | 57.5° | 62.0° | 57.5° | 61.0° | 61.0° | 62.0° |
| 7.6 | 50° | 20 | 62.0° | 66.0° | 60.0° | 61.5° | 60.5° | 63.5° |
| 7.6 | 50° | 30 | 64.0° | 67.0° | 60.0° | 63.0° | 63.0° | 64.0° |
| | | | **Sept. 15, 1939** | | | | | |
| 8.8 | 70° | 0 | — | 88.0° | 65.5° | — | 109.0° | 81.5° |
| 8.8 | 70° | 1 | 77.5° | 81.0° | 63.0° | 99.0° | 102.5° | 74.5° |
| 8.8 | 70° | 3 | 69.5° | 71.5° | 62.0° | 90.5° | 89.0° | 70.0° |
| 8.8 | 70° | 10 | 65.0° | 67.5° | 61.5° | 69.0° | 69.5° | 64.0° |
| 8.8 | 70° | 20 | 63.0° | 67.0° | 61.0° | 66.0° | 65.0° | 63.0° |
| 8.8 | 70° | 30 | 63.5° | 65.5° | 60.0° | 64.5° | 64.0° | 63.5° |
| | | | **Sept. 19, 1939** | | | | | |
| 5.8 | 55° | 0 | — | 70.5° | 58.0° | — | 84.5° | 68.0° |
| 5.8 | 55° | 1 | 63.5° | 65.0° | 57.0° | 79.5° | 79.5° | 64.0° |
| 5.8 | 55° | 3 | 58.5° | 60.5° | 57.0° | 74.0° | 73.0° | 63.0° |
| 5.8 | 55° | 10 | 62.5° | 64.5° | 60.0° | 63.5° | 63.0° | 62.5° |
| 5.8 | 55° | 20 | 67.0° | 68.0° | 61.5° | 64.0° | 64.0° | 64.0° |
| 5.8 | 55° | 30 | 66.0° | 68.0° | 61.5° | 65.0° | 64.5° | 64.0° |

*Reading secured under one of the larger stones at the center of an area some 4 feet in diameter where 65% of the surface soil was covered by a single layer of flat stones with sizes ranging from 2 to 10 inches the long dimension.

†Straw mulch 6 tons of oat straw per acre applied August 1939.

## TEMPERATURE OF FIELD SOILS UNDER SURFACE STONES AND STRAW MULCH ON SMALL FIELD PLOTS

The soil temperatures were usually higher at the 1-inch depth under the stones (Table 4) than under the fallow at the same depth. The fallow temperatures were 14° to 24.5°F higher at the 1-inch depth than under the straw. It appears that the low temperatures under the straw caused less evaporation. The higher temperatures under the stones would counteract to a certain extent the tendency of the stones to reduce evaporation through obstructing diffusion of the vapor into the atmosphere.

## EFFECT OF SURFACE STONES ON SOIL MOISTURE OF FIELD SOILS ON SMALL FIELD PLOTS

The tension of the soil water under the 4-inch layer of stones was consistently lower than under 65% stone cover, and the latter was lower than that under normal stone cover (Table 5). Shifting the stone cover treatment to different locations did not change the trends. Apparently, the differences in soil moisture behavior were due to the treatments and not to soil variation. With lower air temperatures and less sunshine in the second period, there was a tendency for the 65% stone cover to increase in effectiveness as a mulch.

TABLE 5.—*The average tensions of soil water under various stone covers for two periods of time in 1941.*

| | Stone cover | | | | |
|---|---|---|---|---|---|
| | Stone removed | 18% | 65% | 100%, 4 in. | 100%, 8 in. |
| | Aug. 16 to Sept. 15* | | | | |
| Plot No. | 5 | 3 | 4 | 2 | 1 |
| Tension 3 in. depth† | 35 | 36 | 21 | 6 | 10 |
| Tension 10 in. depth | 26 | 24 | 21 | 5 | 13 |
| Tension 20 in. depth | 36 | 38 | 39 | 18 | 37 |
| | Sept. 24 to Oct. 14‡ | | | | |
| Plot No. | 4 | 2 | 1 | 5 | 3 |
| Tension 3 in. depth | 39 | 47 | 17 | 12 | 10 |
| Tension 10 in. depth | 28 | 36 | 14 | 11 | 10 |
| Tension 20 in. depth | 33 | 28 | 23 | 26 | 20 |

*Rainfall, August 16 to September 15, 1.87 inches.
†Tensions are in cm of mercury at indicated soil depths.
‡Rainfall September 24 to October 14, 1.22 inches. Covers were removed and reestablished on plots as shown under plot number.

There seems to be little difference between the stone removed and natural stone cover treatments, and the same was true for the 4 inches and 8 inches of stone cover. The treatments were not continued long enough to influence to any appreciable extent the moisture content of the soil at the 20-inch depth. The difference in moisture condition of the surface soil was probably related to difference in loss by evaporation since the rains were gentle and little runoff

occurred during the studies. Water applied during the interval between periods was applied no faster than could be absorbed without runoff.

## DISCUSSION

Since surface stones increase water absorption, decrease soil washing, and apparently reduce evaporation, there seems to be little reason for removing them from fields unless they definitely interfere with cultivation.

In New York the best sites for growing grapes and other fruits are the sloping lands adjacent to large bodies of water. Clean cultivation, especially where rows are off the contour, results in severe erosion. Many of these soils are stony and it may be advisable to use cultivating tools that work stones to the surface, such as the spring tooth harrow. Once a stone mulch is established, weeds might be controlled by toxic sprays, which later act as a nitrogen fertilizer to the grape vines or trees.

The high temperatures under stones may be one factor in the production of high-quality grapes on stony steep slopes. It may also help explain yields of over 50 bushels of corn per acre at the high altitude of the Arnot Station.

The low temperatures under a straw mulch could also help account for the success of such cool season crops as potatoes grown under a straw cover in the high summer temperatures of southwestern Illinois.

## SUMMARY AND CONCLUSIONS

This study to determine the effect of surface stones on soil erosion and soil moisture was carried out to save many farmers the labor of unnecessary stone removal. Soil and water runoff from field plots was collected and weighed, and soil moisture and soil temperature conditions were noted. Soil in special boxes was weighed to determine the water loss by evaporation from the surface.

The removal of surface stones above 2 inches largest dimension on field plots approximately doubled the water runoff and increased soil loss as much as six fold.

A 65% stone cover compared to the normal 18% stone cover over the soil in weighed boxes slightly reduced the loss of soil water by evaporation, increased water absorption, decreased soil loss, and maintained a relatively high water-holding capacity.

A 6-ton per acre straw mulch cover over the soil in weighed boxes reduced the loss of water by evaporation, greatly increased water absorption, prevented soil loss, and maintained a high water-holding capacity.

A 65% stone cover on field plots increased soil temperatures and maintained a higher content of soil moisture than the 18% stone cover. A 4-inch layer of stones maintained a higher content of soil moisture than the 65% stone cover.

A straw mulch of 6 tons per acre gave soil temperatures at 1-inch depth as much as 24°F lower than at similar depths under the 18% stone cover.

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# WHEAT VARIETAL REACTION TO DWARF BUNT IN THE WESTERN WHEAT REGION OF THE UNITED STATES[1]

C. S. Holton and C. A. Suneson[2]

THE growing of resistant varieties offers the only known method of controlling dwarf bunt, a disease now widely prevalent in sections of Montana, Idaho, Utah, and Washington. Fortunately, many of the varieties used in breeding for resistance to the ordinary bunt (2)[3] are also resistant to dwarf bunt.

Pathological researches and general observations have demonstrated several characteristics peculiar to dwarf bunt which are pertinent to practical control of the disease. Dwarf bunt attacks fall-sown wheat only and thus can be controlled by growing spring wheat. It appears to be largely soil-borne (1), thus precluding effective control by seed treatment. It cannot be reproduced effectively by seed inoculation with chlamydospores (4), thus increasing the difficulty of experimentation.

Isolated new outbreaks and local spread of dwarf bunt with instances of damage exceeding 75% have been observed during surveys in recent years. The disease has persisted in certain fields in Utah for more than 10 years under alternate cropping and fallow, despite intervening culture of varieties equal to Ridit in resistance. In the 1942 uniform dwarf bunt nursery at Clarkston, Utah, in a field thrice previously cropped to a resistant variety, infections ranged up to 90% in susceptible varieties. On the other hand, in northern Idaho, infestation in susceptible varieties such as Golden has declined appreciably since 1938, coincident with increased rainfall, introduction of crops other than wheat, and elimination of fallow. It is evident that adequate information on the causal organism and on the influence of environmental and ecological factors on the development of dwarf bunt in epidemic proportions is lacking. However, additional information on varietal resistance presented here should be helpful. The reaction of certain hard red winter wheats to dwarf bunt has been reported by Rodenhiser and Quisenberry (3).

## MATERIAL AND METHODS

Fifty-two winter wheats, including commercial varieties, hybrid selections of potential value as commercial varieties or parent stocks, and varieties used in physiologic race identification were grown for 2 to 6 years in uniform nurseries at five locations. Nurseries were grown for 6, 5, 4, and 2 years, respectively, at Logan, Utah; Bozeman, Mont.; High Prairie, Wash.; and Malad and Troy, Idaho. High

[1]Cooperative investigations of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Agricultural Research Administration, U. S. Dept. of Agriculture, and the agricultural experiment stations of Washington, Idaho, Utah, and Montana. Received for publication February 11, 1943.

[2]Pathologist and Agronomist, respectively, Division of Cereal Crops and Diseases, Bureau of Plant Industry. The authors express appreciation to D. C. Tingey, R. W. Woodward, H. Stevens, R. H. Bamberg, and R. Sprague for their participation in these tests.

[3]Figures in parenthesis refer to "Literature Cited", p. 583.

TABLE 1.—*The reaction of 52 varieties and hybrid selections of winter wheat to dwarf bunt in uniform nurseries grown at five locations in the western wheat region of the United States.*

| Variety | C.I. No. | Nursery location, year tested, and percentage dwarf bunt | | | | | | | | | | | Weighted average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | High Prairie, Wash. | | | Bozeman, Mont. | | | Logan, Utah | | Malad, Idaho | | Troy, Idaho | |
| | | 1937 | 1938 | 1940 | 1938 | 1940 | 1942 | 1937 | 1942 | 1938 | 1940 | 1940 | |
| Jenkin × Ridit | 10081 | 0 | — | — | — | — | — | 0 | — | — | — | — | 0.0 |
| Hussar | 4843 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0.5 |
| Relief × Ridit | 11908 | — | — | 0 | — | 0 | 2 | — | 0* | — | 0 | 1 | 0.5 |
| Relief × Ridit | 11909 | — | — | 0 | — | 1 | — | — | — | — | 1 | 1 | 0.8 |
| Martin | 4463 | 0 | 3 | 0 | 1 | 0 | 2 | 0 | 2 | 0 | 1 | 0 | 0.8 |
| Relief | 10082 | 0 | 0 | 0 | 1 | 0 | 4 | 0 | 1* | 0 | 3 | 0 | 1.0 |
| Ashkof | 6680 | 0 | — | — | — | — | — | 2 | — | — | — | — | 1.0 |
| Ridit × Relief | 11925 | — | — | — | — | — | 1 | — | 1* | — | — | — | 1.0 |
| Relief × Ridit | 11905 | — | 0 | 1 | 1 | 0 | — | — | — | 5 | 0 | 1 | 1.1 |
| Oro × Turkey-Florence | 11864 | 0 | 0 | — | 3 | — | — | 3 | — | 0 | — | — | 1.2 |
| Relief × Ridit | 11904 | — | 0 | 2 | 2 | 0 | — | — | — | 4 | 1 | 0 | 1.3 |
| Hard Federation × Martin | 11692 | 0 | — | — | — | — | — | 3 | — | — | — | — | 1.5 |
| Beloglina × Hussar | 11513 | 1 | 1 | 6 | 1 | 1 | — | 3 | — | 0 | 0 | 1 | 1.5 |
| Hussar × Hohenheimer | 10068–1 | 0 | 0 | 0 | 11 | 1 | 7 | 2 | 1 | 0 | 1 | 0 | 2.0 |
| Turkey selection | 11530 | 0 | 0 | 0 | 5 | 0 | 7 | 4 | 3 | 0 | 0 | 3 | 2.0 |
| Rex | 10065 | 0 | 0 | 0 | 9 | 5 | — | 7 | — | 0 | 0 | 0 | 2.3 |
| Hymar | 11605 | 0 | 0 | 0 | 10 | 0 | 8 | 1 | 6* | 5 | 0 | 1 | 2.8 |
| Requa | 11554 | — | — | — | — | — | 4 | — | 2* | — | — | — | 3.0 |
| Oro × Turkey-Florence | 11865 | 0 | 0 | 1 | 8 | 1 | — | 22 | — | 0 | 1 | 0 | 3.6 |
| Minturki | 6155 | 0 | 2 | 5 | 5 | 7 | 3 | 0 | 18 | 1 | 2 | 1 | 4.0 |
| Oro × Federation | 11914 | — | — | 12 | — | 3 | — | — | — | — | 1 | 0 | 4.0 |
| White Odessa | 4655 | 0 | — | — | — | — | 6 | 6 | 4 | — | — | — | 4.0 |
| Oro × Federation | 11913 | — | — | 8 | — | 2 | — | — | — | — | 0 | 13 | 5.8 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ridit × Hohenheimer | 11760 | 1 | 0 | 0 | 24 | 2 | — | 30 | — | 1 | 0 | 0 | 6.4 |
| Albit | 8275 | 0 | 0 | — | 28 | — | 5 | 5 | 7 | 1 | — | — | 6.6 |
| Ridit | 6703 | 0 | 1 | 16 | 9 | 8 | 18 | 11 | 5* | 0 | 0 | 7 | 6.8 |
| Rex selection | 11689 | 0 | 0 | 1 | 28 | 0 | 13 | 15 | 7* | 0 | 2 | 12 | 7.0 |
| Ridit × Utah Kanred | 11598 | 0 | — | — | — | — | — | 15 | — | — | — | — | 7.5 |
| Ridit × Utah Kanred | 11686 | 1 | — | — | — | — | — | 15 | — | — | — | — | 8.0 |
| Ridit × Utah Kanred | 11599 | 0 | — | — | — | — | 14 | 13 | 7* | — | — | — | 8.5 |
| Ridit × Utah Kanred | 11597 | 0 | — | — | — | — | — | 18 | — | — | — | — | 9.0 |
| Ridit × 15a | 11924 | — | — | — | — | — | 20 | — | 2* | — | — | — | 11.0 |
| Brevon | 11912 | — | — | 1 | — | 0 | 14 | — | 63* | — | 0 | 5 | 13.8 |
| Hohenheimer × Gold Coin | 11698 | 1 | — | — | — | — | — | 32 | — | — | — | — | 16.5 |
| Hohenheimer | 11458 | 0 | 0 | 10 | 38 | 1 | 7 | 83 | 55 | 1 | 4 | 0 | 18.0 |
| Oro | 8220 | 4 | 11 | 30 | 49 | 19 | 58 | 37 | 20 | 1 | 0 | 18 | 22.5 |
| Oro × Hybrid 128 | 11757 | 5 | 22 | — | 34 | — | — | 58 | — | 15 | — | — | 26.8 |
| Oro × Hybrid 128 | 11758 | 3 | 12 | — | 43 | — | — | 55 | — | 23 | — | — | 27.2 |
| Turkey selection | 10016 | 9 | — | — | — | — | — | 56 | — | — | — | — | 32.5 |
| Oro × Hybrid 128 | 11756 | 13 | 22 | — | 38 | — | — | 66 | — | 25 | — | — | 32.8 |
| Turkey selection | 11424–14 | — | — | 83 | — | 7 | — | — | — | — | 14 | 30 | 33.5 |
| Kharkof | 1442 | 15 | 11 | 53 | 43 | 41 | — | 88* | — | 7 | 38 | 10 | 33.9 |
| Turkey × Hohenheimer | 11759 | 4 | 25 | — | 52 | — | — | 69 | — | 25 | — | — | 35.0 |
| Turkey | 6175 | 19 | 30 | 83 | 47 | 13 | — | 76 | — | 25 | 27 | 21 | 37.8 |
| Rio | 10061 | 11 | 55 | 60 | 20 | 16 | 68 | 74 | 75* | 30 | 20 | 34 | 42.0 |
| Carlson's Fife | 11922 | — | — | — | — | — | 40 | — | 50* | — | — | — | 45.0 |
| Turkey selection | 11424–8 | — | — | 80 | — | 7 | — | — | — | — | 53 | 55 | 48.7 |
| Hybrid 128 | 4512 | 19 | 58 | 50 | 64 | 20 | 78 | 91 | 90 | 35 | 25 | 35 | 51.4 |
| Turkey selection | 11376 | 35 | — | — | — | — | — | 74 | — | — | — | — | 54.5 |
| Yogo | 8033 | — | — | — | — | — | 53 | — | 65 | — | — | — | 59.0 |
| No Name | 12301 | — | — | — | — | — | 58 | — | 83 | — | — | — | 70.5 |
| Elgin | 11755 | — | — | — | — | — | 63 | — | 90* | — | — | — | 76.5 |

*Approximately the same percentage of dwarf bunt occurred on these varieties grown in the Winter Wheat Yield Nursery at Logan, Utah, in 1942, except for Brevon and Carlson's Fife, which had only 7 and 15% dwarf bunt, respectively.

infection percentages did not always occur. Consequently, usable data were obtained for only 2 years each at Logan and Malad, 3 years at Bozeman and High Prairie, and 1 year at Troy. Certain varieties were tested only 1 year and then discarded for various reasons.

Each variety was grown in duplicate rows at each station, the length of the rows averaging approximately 8 feet. The seed of all varieties was rendered smut-free by the treating process already described (2), and the treated seed was sown in soil that was presumed to be naturally contaminated with dwarf bunt spores. In some instances dwarf bunt spores were added to the soil at planting time, but there is no consistent evidence that better infection was obtained because of this artificial inoculation.

The percentages of dwarf bunt were determined on the basis of estimated total and smutted heads in a row. Usually actual counts were made on several rows in each nursery for the purpose of checking the accuracy of the estimates, which were always found to be accurate enough for the purpose of the experiments.

The data from Malad, Idaho, were obtained from the uniform bunt nurseries, described in a previous report (2), in which high infection with ordinary bunt also occurred. The determination of the reaction to both bunts was possible because of their distinct characteristics, though as is shown later, dwarf bunt was sometimes suppressed.

## EXPERIMENTAL RESULTS

The data obtained are presented in Table 1 which gives the percentage infection at each station each year and the average for all stations weighted according to the number of years tested. Because all varieties were not grown at all stations in all years and because the infection level for stations and years was not always the same, a comparison based on the average is not strictly accurate. It is believed to be sufficiently so, however, for the purposes of this paper. The varieties are ranked according to the weighted average for all stations and years.

These averages show that 31 of the 52 varieties and selections tested had less than 10% dwarf bunt. Infection in the others ranged from 11% in C.I.[4] 11924 to 76.5% in Elgin. Among the resistent varieties are the commercial wheats Relief, Rex, Requa, Hymar, Minturki, Albit, and Ridit, while the susceptible group includes Oro, Kharkof, Turkey (C.I. 6175), Rio, Carlson's Fife, Hybrid 128, Yogo, No Name, and Elgin. Most of the hybrid selections tested are in the highly resistant group. The commercial varieties Relief, Ridit, and Oro comprise one or both parents in all but three of these selections. Only one variety, Jenkin × Ridit (C.I. 10081), showed no infection, but it was grown only 1 year at two stations and probably would have shown some infection in more extensive tests.

Among the different stations the heaviest infections were obtained at Logan, Utah, and the lowest at Troy, Idaho. These differences in infection may be due to differences in the physiologic races of the dwarf bunt organism present or in environmental factors influencing infection.

The results obtained with Oro are somewhat conflicting. This variety showed little dwarf bunt at Malad, Idaho, in contrast to

[4]C. I. refers to accession number of the Division of Cereal Crops and Diseases.

appreciable percentages of infection at the other stations. Oro has been one of the major commercial varieties in the Malad Valley where it frequently has had severe infestations of dwarf bunt. Consequently, the low percentage of infection on Oro at Malad was not due to resistance. The explanation may be that the Malad data were obtained from a bunt-inoculated nursery that carried high percentages of ordinary bunt which attacked Oro. In 1 year Oro showed 73% infection from ordinary bunt. From these results it appears that the ordinary bunt may be more aggressive and thus suppresses the development of dwarf bunt in this variety. Whatever the explanation, the behavior of Oro in the Malad nursery does not reflect its true reaction to dwarf bunt. Furthermore, three Oro × Hybrid 128 selections were fairly susceptible at Malad, as well as at Logan and Bozeman. Also, the infection of Brevon at Logan (63%) probably is not representative, owing to poor stands. Therefore, it would seem unwise to regard any variety as highly resistant to dwarf bunt unless that type of reaction is obtained at all stations where tests are made.

## SUMMARY

The reaction of 52 varieties and hybrid selections of winter wheat to dwarf bunt in the western region was determined by nursery tests in five localities in Washington, Idaho, Utah, and Montana. Smutfree seed was sown in soil presumed to be contaminated with dwarf bunt spores. Infection apparently cannot be accomplished by seed inoculation. Thirty-one of the varieties, including Relief, Rex, Requa, Hymar, Minturki, Albit, and Ridit, had less than 10% dwarf bunt. This indicates that there is ample highly resistant stock for breeding purposes.

The highest infections were obtained at Logan, Utah, and the lowest at Troy, Idaho.

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# IMPROVING AN ANNUAL BROME GRASS, *BROMUS MOLLIS* L., FOR RANGE PURPOSES[1]

P. F. KNOWLES[2]

BY FAR the major proportion of grasses on the Californian ranges are annual species, and most of them are introductions from Europe. These annuals have proved themselves to be extremely well adapted to the environmental conditions in the state, having superseded, under past and present range management practices, the original bunchgrasses that were abundant before settlement by Europeans. After germination of the seeds with the fall rains, and a long seedling period with the cool winter temperatures, the adaptability of these annuals is reflected by an abundant vegetative growth with the warmer temperatures of spring. The disadvantage of these annuals, however, is their seasonal character. They dry up quickly when the spring rains cease, the seeds shatter, and during the long dry summer period they are of little value for forage.

The University of California has underway a program to improve the quantity and quality of the forage grasses on the range. Major emphasis at the present time is placed upon the re-establishment of perennial grasses, particularly of the bunchgrass type. At the same time, however, some consideration has been given to the improvement of annuals, since in all probability they will always remain an important constituent of the range. One typical winter annual species, *Bromus mollis* L., commonly known as soft chess or soft cheat, was chosen for preliminary studies of the breeding possibilities of an annual. Very little is known about the introduction of this species into California. All reports (14)[3] indicate that this species was not present before 1870 but was very abundant in most regions by 1900.

The object of this study was to determine the extent of variation within this species, and, if possible, the relation of this variation to environment.

## LITERATURE

No reports could be found of studies of the variation of natural populations of annual grasses. Turesson (18, 19), in Sweden, and Clausen, Keck, and Hiesey (7), in California, made detailed studies of the variation of natural populations of perennial species with different ecological conditions. The heritably different morphological and physiological plant types associated with the different ecological habitats were termed "ecotypes". Among annual dicotyledons Turesson (18) showed the presence of ecotypes in species of *Atriplex*. Clausen, Keck, and Hiesey (5, 6) have given preliminary reports on their studies of the annual *Madiinae*. The species of this group showed well-defined ecotypes in California.

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[2]Graduate student. The writer is indebted to Dr. R. M. Love, Assistant Professor of Agronomy, University of California, who gave generously of his time to advise on the direction of this study.

[3]Figures in parenthesis refer to "Literature Cited", p. 593.

Years of close grazing has tended to fix a prostrate growth habit in pasture plants. This was shown by studies of Gregor and Sansome (8) with *Lolium perenne* L., *Dactylis glomerata* L., and *Phleum pratense* L., and by more comprehensive studies of the same authors (9) on two forms of *Phleum pratense*. Stapledon (16) demonstrated the same condition in pastures of *Dactylis glomerata*. Anderson and Aldous (1) within collections of little blue stem (*Andropogon scoparius* Michx.) showed that the greatest variation existed between samples collected from regions that were great distances apart and subject to very different environmental conditions. Beddows (4) compared the yields of a number of strains of *B. mollis* but did not relate the variation to the sources of the strains.

## MATERIALS AND METHODS

During the summers of 1940 and 1941 a number of collections of soft chess was made. The location and extent of these collections are given in Table 1.

The "strains" of Table 1 are each the progeny of a single panicle selection. The seed of each panicle selection was sown in a 15-foot row in early November, enough seed being sown to establish one plant in each 9 inches of row, or a total of 21 plants to a row. Five rows were sown to a bulk collection from Santa Cruz County. Rows were 12 inches apart. Every sixth row was sown to the same strain of soft chess which traced back two generations to a single plant. The end plants of each row were not used in studies of the strains.

Until the first of March there was little growth of the seedling plants. The warmer temperatures after this date encouraged vigorous development, but until March 15 there were no marked differences between strains. By April 1, however, there was considerable variation apparent, especially with respect to date of heading. Considerable data were collected from these strains, and the manner of their collection is indicated below.

*Days to head.*—The average number of days from seeding (November 8) to the date at which heading occurred was calculated for each strain. A plant was called headed when the first panicle began to emerge, and the nursery was checked every 6 days in this respect.

*Plant habit.*—Five habit classes, *viz.*, erect (e)[4], sub-erect (se), spreading (sp), sub-spreading (ssp), and decumbent (d) were established. This note was taken shortly after all plants of a strain had headed, and the note was taken on the complete row and not on the individual plants.

*Plant height.*—The height in cm of the tallest tiller of every plant in the nursery was taken, and the mean of each strain calculated.

*Tiller number.*—The number of tillers on all plants was determined just before maturity.

*Plant weight.*—The total dry weight in grams of all plants of a strain was determined, and the plant weight recorded as the mean weight of a single plant.

In late April a large number of the leaves of all plants were affected by a species of *Septoria* with the result that many of the leaves dried up. Smut, *Ustilago bullata* Berk,[5] was found in many of the strains, but in no case was it very severe. Leaf rust (species not determined) started late in the development of the plants and was recorded as a trace in most strains.

[4]Letters in parenthesis indicate the abbreviations for habit classes that are used in the tables.

[5]Species identified by G. W. Fischer, Associate Pathologist (Coop. U. S. D. A.), Washington Agricultural Experiment Station, Pullman, Wash.

Because the check rows showed a consistent variation in certain sections of the nursery, the characters height, tiller number, and weight of each strain were increased or decreased according to the performance of the check. This was done so that strains from different sections of the nursery could be compared.

Pollen mother cells (p.m.c.) for cytological study were obtained from 64 strains of soft chess. An attempt was made to sample the extremes of variation found in the nursery. Studies were carried out using temporary aceto-carmine smears made according to Love's technic (11). A number of photomicrographs were taken, all magnifications being $\times$ 820. Emphasis in cytological studies was placed on the chromosome pairing at first metaphase of meiotic divisions. The number of open and closed bivalents was recorded, as was the number of univalents. From most plants a total of 25 good p.m.c. was used. When first anaphase and tetrad material was available, any departures from the normal behavior were recorded.

## EXPERIMENTAL RESULTS

### REGIONAL VARIATION

Sampson (15) has classified the California ranges according to the life zone where they are found. The zones can be described briefly as follows: The Lower Sonoran includes the Great Valley of California and the Colorado and Mojave deserts; the Upper Sonoran comprises the lower foothill belt of grassland bordering the Great Valley and a slightly elevated chaparral belt between 1,000 and 5,000 feet; the Transition includes elevations between 2,000 and 7,000 feet and is characterized by the forest belt and includes the northern and central coastal areas; and the Boreal occupies the areas from 7,000 feet to the tops of the highest mountains. Bailey's (2) zone map of Oregon was used for that state. Strains of soft chess have been obtained from each of the first three zones, and the data on each of these strains are grouped accordingly in Table 1. Subgroupings are by counties.

The most conspicuous difference between the collections of soft chess from the different life zones was in the time required for heading to take place. The collections from the Transition Zone were distinctly later, and the degree of overlapping of extreme ranges for this character between the Transition and the Upper Sonoran was very small. The strains from the Lower Sonoran averaged earlier than those from the Upper Sonoran, but the degree of overlapping was considerable. Fig. 1 gives some idea of the range in maturity of this species.

Among the other plant characters there were none that exhibited distinct and consistent differences between life zones. Height, on the average, decreased from the Transition to the Lower Sonoran, but there was considerable variation within the zones. Collections from Tuolumne County were conspicuous in the nursery because of their greater height.

### LOCAL VARIATION

One of the purposes in collecting and growing these samples of soft chess was to discover superior strains that might improve this species for range purposes. Consequently, a few counties have

been chosen to illustrate the variation between strains that was found. In Table 2 the data on six consecutive strains from each of three different counties are presented. Some idea of the extent of the variation within all counties can be obtained from Table 1, where for each character the range from the lowest performing strain to the highest is given.

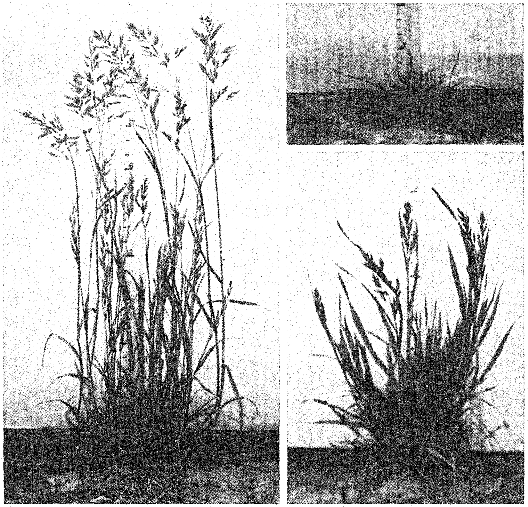

FIG. 1.—Variations in maturity of soft chess, *B. mollis*, from different regions of California and Oregon. *Left*, an example of the early interior ecotype from the Upper Sonoran Zone in Solano County. *Right*, two examples of the coastal or near-coastal ecotype in the Transition Zone, the lower being from Humboldt County, Calif., and the upper from Benton County, Ore. Height scale is in inches.

Table 2 emphasizes that there are differences, sometimes quite wide, in performance among the strains from each county. Sutter County exhibited less variation among its strains than did the other two counties, but even in this county the differences were definite enough to permit the choice of superior strains.

Superior strains have been chosen on the basis of performance for certain agronomic characters. The standard that a strain had to achieve before being selected for further study was: plant weight

TABLE 1.—*Data on plant characters that were obtained from strains of soft chess grown under uniform nursery conditions at Davis, Calif., 1941–42.*

| County | No. of strains | Days to head | | Plant habit range* | Plant height | | Tiller number | | Plant weight | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Range | | Mean | Range | Mean | Range | Mean | Range |
| **Transition Zone** | | | | | | | | | | |
| Benton, Ore. | 13 | 180 | 166–199 | se–sp | 73 | 31–103 | 28 | 18–33 | 18 | 6–30 |
| Lane, Ore. | 3 | 188 | 181–202 | sp–ssp | 74 | 52–85 | 23 | 16–29 | 16 | 7–23 |
| Del Norte | 16 | 186 | 174–201 | se–sp | 88 | 58–102 | 31 | 22–45 | 23 | 7–38 |
| Humboldt | 23 | 174 | 163–183 | e–ssp | 77 | 49–103 | 27 | 17–43 | 23 | 15–43 |
| Santa Cruz | 94 plants | 185 | 169–193 | se–ssp | 99 | 68–121 | 38 | 12–72 | 30 | — |
| Mean† | 55 | 180 | 163–202 | e–ssp | 80 | 31–121 | 28 | 12–45 | 21 | 6–43 |
| **Upper Sonoran Zone** | | | | | | | | | | |
| Contra Costa | 18 | 164 | 155–169 | e–ssp | 80 | 72–89 | 29 | 20–43 | 21 | 14–33 |
| Alameda | 10 | 157 | 151–164 | e–ssp | 74 | 64–87 | 28 | 22–36 | 22 | 17–32 |
| Monterey | 6 | 160 | 158–163 | e–ssp | 81 | 74–89 | 25 | 20–31 | 23 | 18–31 |
| Lake | 5 | 164 | 163–165 | e–sp | 80 | 70–86 | 21 | 19–22 | 20 | 18–23 |
| San Benito | 6 | 156 | 151–158 | e–ssp | 78 | 68–91 | 25 | 19–31 | 22 | 18–26 |
| Napa | 6 | 158 | 153–163 | se–ssp | 77 | 61–95 | 27 | 22–36 | 20 | 16–26 |
| Orange | 5 | 152 | 151–157 | se–d | 58 | 52–71 | 24 | 20–28 | 15 | 12–20 |
| Solano | 44 | 153 | 151–164 | e–ssp | 67 | 55–92 | 33 | 23–62 | 23 | 14–34 |
| Yolo | 9 | 154 | 151–160 | e–ssp | 71 | 57–86 | 40 | 32–49 | 26 | 13–36 |
| Tuolumne | 2 | 158 | 153–162 | e–se | 90 | 79–101 | 27 | 24–30 | 36 | 33–38 |
| Madera | 6 | 159 | 157–162 | e–ssp | 83 | 72–87 | 24 | 21–27 | 20 | 18–22 |
| Mean | 117 | 157 | 151–169 | e–d | 73 | 52–101 | 30 | 19–62 | 22 | 12–38 |
| **Lower Sonoran Zone** | | | | | | | | | | |
| Sutter | 6 | 151 | 151 | se–sp | 60 | 58–63 | 35 | 30–40 | 25 | 21–30 |
| Merced | 2 | 154 | 151–157 | se–ssp | 64 | 57–70 | 24 | 24 | 17 | 14–20 |
| Fresno | 6 | 151 | 151 | sp–ssp | 58 | 55–63 | 30 | 28–33 | 24 | 22–26 |
| Mean | 14 | 151 | 151–157 | se–ssp | 60 | 55–70 | 31 | 24–40 | 23 | 14–30 |

*See page 585 for explanation of letters.
†Santa Cruz material excepted.

TABLE 2.—*Comparisons of strains of soft chess obtained from three different localities in California.*

| Strain No. | Days to head | Plant habit | Plant height, cm | Tiller number | Plant weight, grams |
|---|---|---|---|---|---|
| | | Humboldt County (Transition Zone) | | | |
| B322 | 177 | sp | 75 | 32 | 21 |
| B323 | 180 | se–sp | 64 | 22 | 15 |
| B324 | 181 | sp | 61 | 24 | 20 |
| B325 | 176 | sp | 88 | 38 | 33* |
| B326 | 169 | se–sp | 84 | 36 | 33* |
| B327 | 180 | e–sp | 68 | 32 | 22 |
| | | Solano County (Upper Sonoran Zone) | | | |
| B214 | 153 | se–sp | 70 | 27 | 22 |
| B215 | 157 | e–se | 70 | 35 | 31* |
| B216 | 157 | e | 71 | 34 | 26 |
| B217 | 152 | e–se | 71 | 34 | 25 |
| B218 | 157 | e–sp | 74 | 37 | 28* |
| B219 | 151 | se–sp | 62 | 36 | 25 |
| | | Sutter County (Lower Sonoran Zone) | | | |
| B297 | 151 | se–sp | 63 | 40 | 30* |
| B298 | 151 | se–sp | 58 | 35 | 21 |
| B299 | 151 | se–sp | 58 | 35 | 23 |
| B300 | 151 | sp | 63 | 36 | 30* |
| B301 | 151 | sp | 58 | 33 | 22 |
| B302 | 151 | sp | 62 | 30 | 22 |

*These strains are considered superior and will be kept for further test.

28 grams or more; either the height over 90 centimeters or the tiller number over 35. The selected strains in Table 2 are marked. In Table 3 the source of all superior strains of soft chess is listed.

TABLE 3.—*Source of superior strains of soft chess.*

| Counties with superior strains | Number of strains | | Counties with no superior strains | Total number of strains |
|---|---|---|---|---|
| | Total | Superior | | |
| Transition Zone | | | Transition Zone | |
| Benton, Ore. | 13 | 1 | Lane | 3 |
| Del Norte | 16 | 4 | | |
| Humboldt | 23 | 6 | Upper Sonoran Zone | |
| | | | Alameda | 10 |
| | | | Monterey | 6 |
| Upper Sonoran Zone | | | Lake | 5 |
| Contra Costa | 18 | 1 | San Benito | 6 |
| Solano | 44 | 9 | Napa | 6 |
| Yolo | 9 | 4 | Orange | 5 |
| Tuolumne | 2 | 2 | Madera | 6 |
| Lower Sonoran Zone | | | Lower Sonoran Zone | |
| Sutter | 6 | 2 | Merced | 2 |
| | | | Fresno | 6 |

The better-performing strains presented some interesting situations. Selected strains were obtained from all life zones and included types that were both early and late. Better strains seemed to be more prevalent in certain counties than others. Humboldt, Del Norte, Solano, Yolo, Tuolumne, and Sutter counties contributed more than their share of better-performing strains. Solano and Yolo collections were expected to perform well at Davis—which is located on the boundary of these two counties, but the large contribution of these other counties, especially Humboldt and Del Norte, was not anticipated.

*Type of fertilization.*—A high degree of uniformity existed within each row sown from a single panicle, referred to as a strain in this study. The height and habit, especially, of all plants in each row were very similar. This suggests that soft chess is highly self-fertilized.

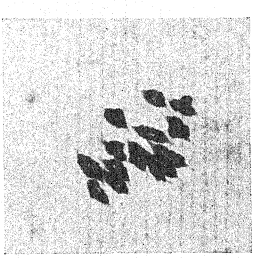

FIG. 2.—Chromosomes (2n = 28) at first meiotic metaphase in a pollen mother cell of soft chess, *B. mollis*.

*Cytological variation.* — The meiotic process in soft chess is stable and uniform. All 64 investigated strains of this species exhibited the same chromosome number (2n=28). The chromosomes at first metaphase are illustrated in Fig. 2. There were few departures from the normal meiotic behavior; the mean number of open bivalents was low, and the mean number of univalents was very low. There were a few tetrads with micronuclei.

## DISCUSSION

Discussions of the taxonomy of soft chess have assumed this species to be monotypic. No mention has been made of any regional differentiation for physiological or morphological characters. When the panicles of soft chess were collected from the different regions of California and Oregon, it was realized that the maturity of the northern and coastal samples was later than those taken from the interior regions of California. This was considered to be due to the fact that in the coastal and northern areas the season had not advanced so far. It appeared as if soft chess had adapted itself to make its most abundant growth under the warm moist conditions at the end of the winter season. Consequently, it was expected that all strains would exhibit much the same growth rhythm when they were grown under the same environmental conditions.

On the basis of the results from this study, however, soft chess, *B. mollis*, can be divided into two ecotypes, *viz.*, (a) a late coastal or near-coastal ecotype from the Transition Zone along the coast of central and northern California and near-coastal regions of Oregon, and (b) an early interior ecotype from the Upper and Lower Sonoran

Zones of California. The coastal ecotype averaged 180 days to head, whereas the interior ecotype was at least a mean of 20 days earlier, averaging 157 days to head for strains from the Upper Sonoran and 151 days for strains from the Lower Sonoran Zone. The association of lateness with coastal environment is true of other plant species.

Clausen, Keck, and Hiesey (5, 6) found many widespread annual dicotyledonous species to behave like *Layia platyglossa*, exhibiting a later maturity on the coast than in the interior regions of California. Among the perennial herbaceous dicotyledons, Turesson (19) showed an association of lateness with the maritime conditions of western Europe, as contrasted with the earliness of samples from eastern Europe. Unpublished studies by Love of the variation of *Stipa pulchra* in California have shown coastal collections from Santa Cruz County to be later than others.

These ecotypes could not be identified by any other characteristic apart from earliness. The mean plant height decreased from the Transition to the Lower Sonoran Zone, but the variation within the Transition Zone overlapped considerably the variation within the Upper Sonoran. There was no tendency for low-growing types to be more prevalent in coastal and northern collections; the only decumbent types were found in the Upper Sonoran Zone, and sub-erect to sub-spreading types were present in all zones. Clausen, Keck, and Hiesey (5, 6, 7) have generally found in annual and perennial dicotyledons that a prostrate habit is associated with the maritime habitat. Turesson (19) also found this association in perennial dicotyledons from the maritime areas of western Europe. Gregor and Sansome (8) reported prostrate types to be more common in coastal forms of *Lolium perenne* and *Dactylis glomerata*, and Stapledon (16) also found this condition to be true of his collections of *D. glomerata*. In each case, however, the prevalence of prostrate types was related to years of close grazing.

What climatic factor is responsible for this regional difference is not known. Cooler, moister atmospheric conditions that prevail along the coast and even in the more interior regions of Oregon may have effected a genotypical selection of plants that were heritably later and better related to the seasonal rhythm of these areas. Further study will be necessary to determine the correct relation between earliness and environment in these strains.

Within the collections from a single zone, from a single county, or indeed, from a single locality, there were wide variations between strains. This was true of all plant characters. Such a variation is to be expected in a dynamic living world, as Clausen, Keck, and Hiesey (7) have emphasized. This may be even more true of this introduced species than it would be of long-established or indigenous species. Perhaps the perfect relation between climate and plant type in soft chess has not yet been realized in California.

The three zones differed in the range of variation among the strains. Within the Transition Zone there were greater differences between the strains for every character than in the other zones, and the Lower Sonoran showed least variation. This was not only true when the zones were compared as a whole, but even the individual counties

within the Transition Zone showed most variation between strains and the counties of the Lower Sonoran Zone showed least variation. The reason for this cannot be explained satisfactorily. Perhaps the removal of the strains from the Transition to the conditions of the Upper Sonoran Zone has emphasized differences; in other words, the Transition strains might be a more homogeneous population under their own environment. Perhaps the environmental conditions of the Transition Zone are less strict in "fixing" certain types.

The existence of such a wealth of variable types offers favorable material to the plant breeder who is interested in improving this species by selection. Most encouraging is the fact that superior types, as measured by yield, tiller number, and height, have been obtained which differed widely in earliness. It may be possible to introduce a later-maturing strain to regions of California where early-maturing forms now exist and thereby prolong the period of green vegetation without detriment to yield. A reservation must be emphasized at this stage. These selections have been tested under artificial conditions and the results may not agree with those that would be obtained under natural conditions. Further tests must involve seeding experiments under range conditions before any definite conclusions can be arrived at concerning the relation of earliness to yield. These strains have been tested for only one year; critical comparisons of strains require the data of a number of years.

The conclusion from these studies that soft chess is highly self-fertilized is supported by the studies of Troll (17), Beddows (3, 4), and Nilsson (12, 13). Troll considered that cleistogamy was the rule, but Beddows (3) did not find it in his material. No cleistogamous strains were found in the present study. No critical data were obtained to indicate the extent of natural crossing that occurred. Some rows showed an occasional plant that seemed to deviate definitely with respect to earliness or general habit. Beddows (3) concluded that cross-pollination was not impossible, and the wide variation of some individual plants (4) among the progenies of single plants confirmed this opinion. The breeding behavior, then, of this species is most like that in the cereal crops, wheat, oats, and barley. This similarity suggests that breeding methods for the improvement of this species should follow those already practiced among the above-mentioned domestic crops.

There was no variation in chromosome behavior or number with the morphological and physiological variation of soft chess. The meiotic behavior of all strains was regular and uniform and the chromosome number was 28 (2n). This would indicate that the variation within this species could be related to genic differences. Clausen, Keck, and Hiesey (7) found a similar situation in *Potentilla glandulosa*. The tremendous range of variation within this species in California was associated with a constant chromosome number ($2n = 14$).

Studies of the ecological response of annual grasses or annual herbaceous dicotyledons under natural conditions are extremely limited. Turesson's studies (18) on the distribution of the ecotypes of the annual *Atriplex* species did not include comparisons of a species

under both maritime and inland habitats. A more complete account of the investigations by Clausen, Keck, and Hiesey upon the annual *Madiinae* is awaited with interest. It seems to the writer that annual plants have not been exploited enough in studies of the relationships between natural populations and climate. Annual grasses, in particular have been ignored almost completely. Annuals are at a disadvantage in transplant experiments; studies would have to be limited to seedings. If the species were cross-pollinated, there would be the difficulty of maintaining "pure" seed stocks. Where self-fertilization is the rule, however, annual species have certain advantages. They usually produce abundant seed, and seed stocks could be built up quickly and could be easily maintained. They complete their life cycle in one year and experimental technic would be speeded up.

A possibility is seen of the annuals serving a valuable role in determining the dynamic nature of the different ecotypes, where ecotypes are available. If it were highly self-fertilized and where readily distinguishable character-differences between ecotypes were available, an annual species could be used under different environments to picture the competition between ecotypes. Harlan and Martini (10) have related the distribution of barley varieties in the United States to the competitive success of the same varieties in varietal mixtures grown in the different barley regions. A similar test could be conducted under more or less natural conditions to compare the competition of ecotypes in ecotype mixtures when they are grown in different ecologic regions.

## SUMMARY

1. Panicle selections of soft chess, *Bromus mollis*, from California and Oregon were grown under uniform nursery conditions and studied to determine the morphological, physiological, and cytological variation.
2. Distinct regional differences were shown to exist for time to head but not for any other character. An early maturing interior ecotype and a later coastal ecotype were demonstrated.
3. Each strain appeared very uniform and distinct from the other strains, suggesting that this species is self-fertilized.
4. Within collections from the same county and from the same locality wide differences were found in the morphological appearance and physiological behavior of the separate strains.
5. Cytologically, soft chess is very uniform among strains, there being no departure from the condition of 28 chromosomes (2n) and no evidence of consistent abnormalities in the meiotic process.
6. Annual species, where ecotypes exist and where they are self-fertilized, are suggested as being of possible value in studies of the dynamic nature of the ecotype.

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# REDUCING THE ERROR IN INFILTRATION DETERMINATIONS BY MEANS OF BUFFER AREAS[1]

F. L. DULEY AND C. E. DOMINGO[2]

INVESTIGATORS interested in the use, disposal, or storage of rainwater have made many attempts to estimate field infiltration rates by means of artificial applications of water to small plots. Different types of equipment and methods have been employed for the purpose. The size of the areas to which water has been applied has varied from a few square inches to several hundred square feet. The methods of applying water have varied from irrigation by flooding with a constant small head over the entire surface to various methods of sprinkling, using a wide range of intensities and size of drops. Certain fundamental principles concerning the relative importance of various surface factors which may affect the rate of intake have been ascertained through the use of these small areas.

The results of most infiltration tests as determined by the use of small areas indicate the capacity of the surface to transmit water under different conditions of soil or surface cover. This information has been of great value, but the infiltration rates obtained do not necessarily represent the absorption that would occur during rainfall. With small areas such as those where tubes have been driven into the ground, or even with small or narrow plots, there may be so much lateral seepage beneath and beyond the plot boundaries that the indicated intake is much higher than would occur over an entire watershed under rainfall conditions. Excavations across small plots after water has been applied for a few hours have shown that the wet soil tends to assume an irregular elongated, globular shape, and may have a mean horizontal cross section several times as large as the plot itself.

Katchinsky (1)[3] attempted to calculate the true permeability of a soil from the extent of the wetted material below and beyond the plot boundaries. Several other investigators (2, 3, 4, 5) have sought to avoid the error in infiltration rates due to lateral seepage by increasing the width or area of the plot or by using concentric areas or multiple square areas where only the inner rings or squares are used for determining intake rates. In some plot tests a larger area has been sprinkled than the plot on which the infiltration measurements have been made. Any of these methods may serve to reduce the variability between duplicate tests, but probably cannot eliminate the fundamental error due to subsurface lateral seepage from any small plot of whatever shape even though it may be several feet in its narrowest dimension.

When water is applied to a small or narrow plot on land that is not saturated, the water descends into the soil as an expanding

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[2]Senior Soil Conservationist and former Cooperative Agent, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 605.

hydraulic wedge. The water pushes the air laterally and moves in to take its place. The air may continue to move laterally under slight pressure or escape to the surface through soil pores or vents. As more water is applied, the volume of wet soil continues to be extended downward and sidewise. The interfacial boundary between this saturated soil and the surrounding soil of lower moisture content can continue to expand in all directions, and thus allow more water to enter through the limited area to which water is applied than would be possible if the water could not move laterally as soon as it is below the surface. Under natural conditions where rain is falling over an entire watershed, the water must pass directly downward into the soil, since extensive lateral movement is prevented because moisture penetration will be at about the same depth over the entire area. Entrapped air can escape only vertically through the soil pores or other vents that may be present in the soil. Since space for extra water cannot be made by sidewise movement, the total amount absorbed as well as the rate of intake will be very much lower when it is raining over the entire surface than when water is applied to small plots.

In the work herein reported, an attempt was made to eliminate the lateral movement of water in infiltration tests, and thereby make possible the determination of infiltration rates more closely in agreement with the rates under rainfall conditions than are now possible through the use of any type of small plots.

## METHODS

### THE SOIL

The soil on which these tests were conducted is a Marshall silty clay loam (heavy subsoil phase). The test site was a 4.6% slope located on a vacant lot on the outskirts of Lincoln, Nebr., close to the city water supply. The soil was relatively dry at the time of the tests, August and September, 1941. The land was in wheat in 1941 but had been used for truck crops most of the time for several years.

### PROCEDURE FOR LARGE PLOTS

Three approximately square plots, each 0.016 acre in area, were laid out on the slope mentioned above. Two opposite corners of a plot were placed on the contour, thus making the other two corners fall in line with the slope. This plot was surrounded with 9-inch strips of sheet metal sunk into the ground to a depth of 6 inches, allowing a 3-inch extension above ground which separated the runoff water within the plot area from that falling outside the plot.

In order to guard against subsurface lateral seepage below the plot boundaries and the loss of some water from the plot area, a saturated buffer zone of soil was put down surrounding the plot. The saturation of this area was accomplished by digging a trench about 4.5 feet outside the plot boundary (Figs. 1A and 2x) entirely around the plot, which left an area between the plot boundary and the buffer zone that received the same treatment as the plot itself. Baffles were placed in the bottom of the trench, and it was then filled with straw to maintain a high intake rate. Water was run through the trench for about 48 hours, after which the straw was removed and the trench filled with soil. This watering had wet the soil in a belt about 7 to 10 feet deep and 3 to 5 feet wide completely around

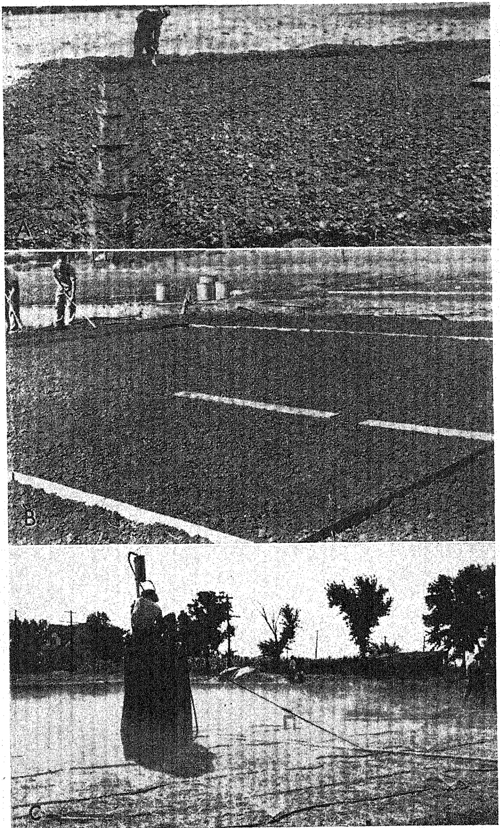


FIG. 1.—Preparation and operation of large plots. A, trench around plot for wetting border; B, condition of surface before straw was applied; C, arrangement of nozzles showing hose connection and type of water distribution. Small plot in center is also shown.

the plot. This saturated soil was equivalent to putting down a wall of water through which soil air would hardly pass. The colloidal material of the soil had sufficient time to swell until water would not pass rapidly through this wet zone.

The soil of the plot was then spaded to a depth of 5 inches and worked down to a seedbed condition (Fig. 1B). The area outside the plot boundary and beyond the trench from which the buffer zone was wetted was similarly treated, the total spaded area being 0.04 acre. This entire area was covered with straw at the rate of 4 tons per acre (Fig. 1C). Previous tests indicated that this amount of straw permitted the maximum intake of water.

In order to sprinkle these plots at the high rates desired, an ample supply of water was obtained from a city fire hydrant. A water meter was set between the source of water and the sprinkling equipment, which consisted of an iron supply pipe to which was attached 30 stationary nozzles by means of rubber hose. One row of these sprinklers (Fig. 2N) was placed outside and completely around the 0.016-acre plot (Fig. 2abcd), which was used for determining the infiltration rate. This ensured a uniform distribution of water over the entire area of this plot. At the same time the land outside the 0.016-acre plot and extending beyond the pre-wetted buffer belt was kept wet by this outside line of nozzles.

These nozzles threw the water upward in a spray having a morning glory shape. Even though each sprinkler distributed the water in a circular area, the overlap was adjusted so that there was a reasonably even distribution of water over the entire area. Since there was a heavy straw cover on the plots, there was less necessity for extreme uniformity of distribution of water over the surface than would be the case if the soil were bare.

The application of water was made during early morning or late afternoon when the rate of evaporation was as low as possible, so that this factor would introduce no important error in the final results. The rate of application varied during the first test on the three large plots from about 3.7 to 4.2 inches per hour. The first application was for 1.5 hours. The second and third applications were each for 3-hour periods and the rate was maintained well above the rate of intake so that there was considerable runoff during most of the time of the second and third tests.

The runoff from the 0.016-acre plot drained out through an opening at the lower corner and was carried down the slope through a 3-inch glavanized iron pipe (Fig. 2-O). The runoff water was caught in a bucket and then measured by pouring into a large calibrated can. Readings were taken at 200-second intervals, so that the difference between application and runoff could be calculated and the infiltration curves plotted.

## SMALL PLOT PROCEDURE

For comparison of infiltration measurements on small plots in comparison with the large ones, a small plot procedure was employed that had previously been used extensively on this project for studying the effects of surface condition and surface protection on intake of water. A rectangular open frame, 16 by 72 inches, was set in the ground to a depth of 9 inches with 3 inches extending above the surface, except at the lower end which was cut out so that it was level with the ground surface. On top of this frame was placed a rectangular metal windbreak extending 6 feet vertically above the box.

For sprinkling this small plot, water was forced by air pressure from a metal tank to a small constant-level supply can placed about 3 feet above the top of the

windbreak (Fig. 1C). A rubber hose attached to the botton of this can was provided at the lower end with a small sprinkler nozzle. By manually swinging this nozzle back and forth, with some widewise shaking, a relatively uniform distribution of water could be obtained.

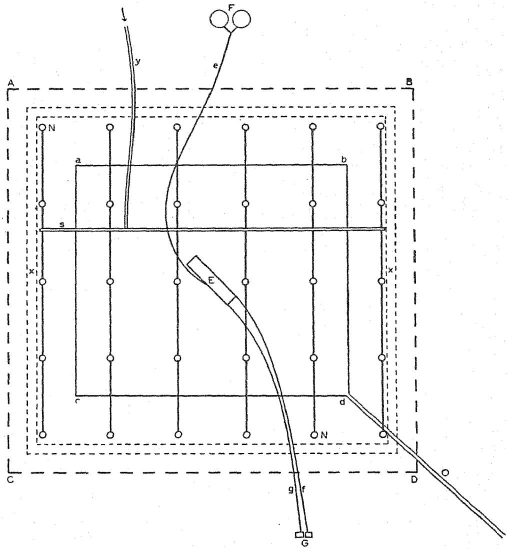


FIG. 2.—Diagram of field plot. abcd, plot 24.53 × 28.4 feet from which runoff was measured, bc on contour; x, trench for wetting buffer zone; y, hose from fire hydrant; s, iron supply pipe; N, sprinkler nozzles connected by rubber hose to supply pipe; E, small plot located inside plot abcd; e, hose from supply tanks F to small plot; g and f, hose for runoff and waste water from small plot E; G, collecting cans; O, pipe to carry runoff from plot abcd to measuring can; ABCD, boundary of entire wetted area. Scale 1 inch = 13.2 feet.

Any water striking the sides of the windbreak was caught in a small gutter and drained away through a small outlet tube at the lower end of the plot, where this waste water was collected and measured. The water running off the plot itself emptied into a small gutter attached to the lower end of the frame at ground level. From here it was carried through a tube to a small container where it was collected and measured. All measurements were taken at 200-second intervals, which made it possible to plot curves showing the rate of intake throughout the course of a test.

The intake of water by these small plots was compared with that of the large ones, using the procedure already described for each type of plot. The comparative intake was determined for two sets of conditions. In one case the small plots were in the open field away from the large plots with no precautions taken against sub-surface lateral seepage of water beyond the bounds of the small plot. The other condition was with the small plot set in the middle of the large plot (Fig. 2E) and the application of water made simultaneously to each. In this case it was assumed that the water would penetrate below the small plot at the same rate as on the large plot, and therefore lateral movement of water from beneath the small plot would not take place. In each case the soil condition and cover used were identical with that of the large plots.

## RESULTS

The total intake and the infiltration rate at the end of each test period are given in Table 1. The first test, which was for 1.5 hours, produced no runoff on any of the plots and served mainly for bringing the plots to a similar degree of wetness so that runoff might take place the more readily at the next run.

TABLE 1.—*Intake of water on large and small plots and final intake rates in inches per hour, August–September, 1941.*

| Plot | Intake, surface inches | | | | Final rate of intake, inches per hour | | |
|---|---|---|---|---|---|---|---|
| | Test 1, 1½ hrs. | Test 2, 3 hrs. | Test 3, 3 hrs. | Total | Test 1, 1½ hrs. | Test 2, 3 hrs. | Test 3, 3 hrs. |
| Large Plots with Wetted Borders | | | | | | | |
| L3 | 5.64 | 5.06 | 3.84 | 14.54 | 3.75 | 1.10 | 0.70 |
| L4 | 6.42 | 2.89 | 2.39 | 11.70 | 4.25 | 0.45 | 0.35 |
| L5 | 5.44 | 5.26 | 3.32 | 14.02 | 3.65 | 1.05 | 0.70 |
| Mean | 5.83 | 4.40 | 3.18 | 13.42 | 3.88 | 0.87 | 0.58 |
| Small Plots Inside Large Plots | | | | | | | |
| 81* | 5.55 | 4.19 | 3.88 | 13.62 | 3.50 | 1.00 | 0.75 |
| 82† | 5.72 | 2.93 | 2.15 | 10.80 | 3.80 | 0.30 | 0.25 |
| Mean | 5.64 | 3.56 | 3.02 | 12.21 | 3.65 | 0.65 | 0.50 |
| Small Plots Without Wetted Borders in Open Field | | | | | | | |
| 83 | 5.17 | 10.32 | 7.08 | 22.57 | 4.00 | 3.15 | 2.00 |
| 84 | 6.02 | 9.54 | 8.82 | 24.38 | 4.00 | 3.00 | 2.70 |
| Mean | 5.60 | 9.93 | 7.95 | 23.48 | 4.00 | 3.08 | 2.35 |

*Inside plot L3.
†Inside plot L4.

During the second and third runs, water was applied at rates well in excess of intake. Therefore, the amounts of water absorbed during these runs represent the maximum capacity of the soil to absorb water under the conditions employed.

In the case of the large plots, there was considerable spread between the absorption on plots L3 and L4, but plot L5 was in very

close agreement with plot L3. This might raise a question as to the number of such plots needed to obtain a satisfactory determination of intake capacity of a given soil. It would seem reasonable that the degree of accuracy should be increased by use of the large plot, but there is often difficulty in finding large areas that are as uniform in all respects as would be desired. Such lack of uniformity may have been one reason the absorption by L4 was lower than had been expected.

If the results obtained on the small plots, 81 which was within L3, and 82 which was within L4, are considered, there is good agreement between the large and small plots in each case. The total intake of L3 was only about 6.7% greater than for 81, and the intake of L4 was 8.3% greater than for the small enclosed plot 82. This shows that by giving the small plots the protection of the surrounding soil water of the larger plots, approximately the same results were obtained on each.

The small plots in the open field away from the large plots gave widely different results from either the large plots or the enclosed small ones. The mean total intake of water for the three application periods was 75% higher on the small plots in the open field than on the large plots protected with a buffer strip and a saturated belt of soil, and 92% greater than for the small enclosed plots. These results clearly indicate that much water had escaped from beneath the small plots in the open by subsurface lateral seepage, and the results were accordingly much higher than on the large or small plots where the water had been forced to go directly downward into the soil.

The infiltration curves for one large plot, L3, and for the mean of the two small plots 83 and 84 in the open field, based on intake measurements taken at 200-second intervals, are shown in Fig. 3. Curves A and D really represent only the rates of water application, since there was no runoff. The infiltration capacity of the soil at that time was therefore higher than the position of these curves indicate. The infiltration curves B and C for the large plot are lower throughout and come to a substantially constant value at a much lower point than do curves E and F, representing rate of intake by the small plots in the open field. This indicates that the water on the small plots was escaping from beneath the plots at approximately a constant rate, which enabled more water to be taken in at the surface than on the large plots where the water was forced to go directly downward.

The soil moisture to a depth of 10 feet before and after the tests on the large plots L3 and L4 were made is shown in Table 2. The data showing the moisture after sprinkling were obtained as the mean of three cores on each plot. This accounts for the apparent tapering off of moisture in the 7- to 9-foot zone, since the moisture had not penetrated to the same depth in all sample locations. If it had done so, the break in moisture would have been abrupt, since water moving downward into a dry soil tends to advance as a front. It is to be noted that there was no increase in moisture in the tenth foot.

By converting the percentage increase in soil moisture after watering to surface inches, it was indicated that 12.45 inches had been stored in this soil. The water meter readings of the amount of appli-

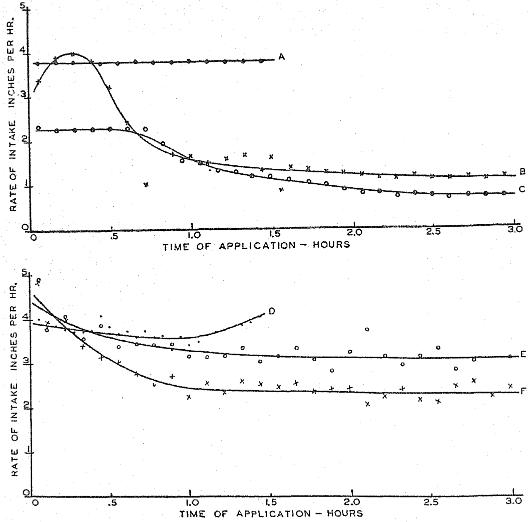


FIG. 3.—Infiltration curves. *Above*, large plot L3, A, first test, no runoff; B, second test; C, third test. *Below*, small unprotected plots, D, first test, rise in curve at end due to increase in application, no runoff; E, second test; F, third test.

TABLE 2.—*Soil moisture content at time of tests, percentage moisture on basis of dry soil.*

| Plot | Depth, feet | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| | Before Sprinkling | | | | | | | | | |
| Field area L3 and L4 | 12.4 | 15.3 | 15.6 | 15.9 | 16.4 | 16.9 | 17.7 | 17.3 | 17.2 | 16.7 |
| | After Sprinkling | | | | | | | | | |
| L3 | 29.4 | 27.6 | 25.0 | 23.6 | 24.0 | 24.3 | 22.9 | 20.8 | 19.6 | 16.7 |
| L4 | 33.3 | 27.9 | 24.9 | 25.0 | 25.7 | 22.6 | 21.6 | 19.9 | 19.1 | 16.5 |
| Mean | 31.3 | 27.7 | 24.9 | 24.3 | 24.9 | 23.4 | 22.3 | 20.3 | 19.4 | 16.6 |
| Increase, % | 18.9 | 12.4 | 9.3 | 8.4 | 8.5 | 6.5 | 4.6 | 3.0 | 2.2 | −0.1 |
| Increase, surface inches* | 2.97 | 2.18 | 1.73 | 1.45 | 1.46 | 1.07 | 0.76 | 0.49 | 0.36 | −0.02 |

*Total surface inches increase 12.45.

cation, minus the amount lost in the runoff, indicated that 13.12 inches had been absorbed by plots L3 and L4. This close agreement indicates that water must have gone directly downward into the large plots and that none had been lost by lateral movement of water within the soil.

## DISCUSSION

Since large plots surrounded by a buffer watered area and also by a prewetted belt gave results indicating that applied water had gone directly downward in the soil and none had been lost by lateral seepage, it appeared that the intake closely represented the intake possibilities of the soil. The results should approximate the possibilities for intake under natural conditions, were it raining over an entire watershed where soil and surface conditions were the same as used in these tests. The results appeared to be much more accurate than the larger amounts of intake on small plots in the open field without protection from lateral seepage. For any hydrologic work where total intake capacity of watersheds is desirable, it would seem that determinations made by the large plot method would be much more directly applicable.

So far this method has been used on only a single soil, but since it appears to give results approaching maximum intake capacities, it might be of much value to have such determinations for a wide range of soils.

There are certain disadvantages in the use of the large plots as compared with the small ones, in that tests are more difficult to make. It is often difficult to select a group of large plots where the soil conditions are as uniform as would be desired. More time and labor are involved, and the original cost of equipment may be somewhat higher, however, this is not excessive. Since large quantities of water are necessary, it is desirable to locate near a large water supply, such as a city water main or a clear water reservoir. The sprinkling equipment used in these tests would not be entirely suitable for testing bare soils, since the water was not thrown very high and the impact of the drops would be too small. Also, the distribution of water in circular areas was probably not as uniform as would be desired for bare soils. Furthermore, the type of large plot used in these tests will probably have its greatest value in determining maximum intake capacity of soils, since it is during such tests that small plots give their greatest error from subsurface lateral seepage.

In these tests only one size of large plot was used, and therefore it is not yet possible to say what minimum size would be possible for satisfactory results if provision were made to avoid lateral seepage. The small plots inside the large ones gave results comparable with those of the large plots, but methods have not yet been devised for adequately protecting the small plots against lateral seepage when a large wetted area is not used to surround it.

The small infiltrometer has been extensively used by many investigators and much valuable information has been obtained with it, particularly with regard to evaluating the effect of different surface conditions or types of residue on intake of water by the surface

soil. Since the use of small areas permit so much loss of water by lateral seepage, the principal information obtained from the use of this type of equipment is confined to surface phenomena. Such tests show the capacity of the surface to transmit water rather than the rate at which water might be absorbed by the soil profile during rainfall. If the use of the small unprotected infiltrometer is confined to this limited field and not used for determining intake capacity, it has possibilities of yielding much additional information.

## SUMMARY


A method is described for determining the infiltration capacity of a soil by using large plots protected against loss of applied water through lateral seepage.

Approximately square 0.016-acre plots were laid out on a 4.6% slope and surrounded by metal borders sunk into the ground to a depth of 6 inches. Surrounding the plot was a border space which had the same treatment as the plot itself. About 4.5 feet outside the plot lines a trench was dug and water run through this until a belt of soil 7 to 10 feet deep around the plot was saturated. This served as a buffer area through which water and air could not pass laterally from the plot area on which infiltration tests were to be made.

The plot together with the border area was spaded and covered with straw and then sprinkled by means of a multiple set of stationary sprinklers. The runoff from the 0.016-acre plot was collected and measured, and the total intake and infiltration rate determined.

A small plot, 16 by 72 inches, was placed in the middle of the 0.016-acre plot area and given the same preparation and straw treatment. The application of water and runoff were determined by a special system entirely separate from that used on the large plot.

The results show that the intake of water on the large plots and on the small plot within were similar.

Other of these small plots were placed in the open field where they had no water applied to the surrounding soil and no wet buffer belt to prevent lateral movement of air or water.

The intake on these isolated small plots having no prewetted border protection was 75% greater than for the large plots. These results indicated that lateral movement of water had allowed these small plots to take in more water than would be possible if it were raining over the entire surface.

Since the large plots were protected against lateral movement of water beneath the surface, the results on these plots should represent about what would be the intake possibilities if rain were falling over an entire watershed having the same soil and surface conditions as did these plots.

The method used on these large plots might provide a means for determining with a fair degree of accuracy the infiltration capacities of a wide range of soils and surface conditions under natural rainfall.

The method might be made to supplement the use of small plots when total intake capacities rather than the effect of specific surface treatments on intake are desired.

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# COMPETITION IN COTTON VARIETY TESTS[1]

T. R. RICHMOND[2]

IN DESIGNING experiments to test the yields of varieties of cotton, it is important to know to what extent intervarietal competition may be expected to affect the yields of the varieties. Intervarietal competition either has been found by test or assumed in many field crops, and the effect of the competition in yield trials of these crops has been eliminated by protecting the plot area to be harvested with border plantings of the same variety. If it can be demonstrated that the effect of the intervarietal competition in cotton is not significant, no precision in testing will be gained by protecting the plot area to be harvested with border rows. Under such conditions the width of the plot may be reduced to a minimum or a single row. On the other hand, if cotton varieties differ in their ability to compete, a bias resulting from intervarietal competition will be introduced in tests in which single-row plots are used. Even if some intervarietal competition can be demonstrated, the lower experimental error expected when single-row plots are used, as compared to the experimental error of tests employing multiple-row plots in which more than one row is harvested for yield, may increase the precision of the test as much or more than the elimination of competition between varieties through use of border rows. Furthermore, the additional area occupied by multiple-row plots adds considerably to the expense of conducting a variety test.

Investigators who have worked on this problem are not in full agreement as to the effects of intervarietal competition on variety tests of cotton. Christidis (1)[3] from experiments at the Greek Cotton Institute found significant differences between varieties grown in adjacent, unprotected rows and concluded that, "The results . . . . seem to suggest that competition may cause a definite bias in estimating the comparative yielding value of cotton varieties."

Quinby, Killough, and Stansel (3) conclude from studies at three locations in Texas that, ". . . . cotton varieties differ but little in ability to compete, that varieties compete the same in a favorable as in an unfavorable season, and that single-row plots can safely be used."

Hancock (2), in Tennessee, conducted an experiment with two varieties of cotton, California Acala and Delfos 6102, which, from previous trials, appeared to differ considerably in plant growth. The two varieties were arranged in single-row plots in such a way

[1]Contribution from the Division of Agronomy, Texas Agricultural Experiment Station, College Station, Texas, and the Division of Cotton and Other Fiber Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Technical paper No. 690, Texas Agricultural Experiment Station. Received for publication April 1, 1943.

[2]Associate Agronomist, Bureau of Plant Industry, and the Texas Agricultural Experiment Station. The author acknowledges the assistance of Mr. Charles F. Lewis, Agent, and Roy E. Harper, formerly Junior Botanist, Bureau of Plant Industry, in statistical calculations.

[3]Figures in parenthesis refer to "Literature Cited", p. 612.

that a given variety received three possible border effects, i. e., bordered on each side by the same variety, bordered on one side by the same variety and on the other side by the other variety, and bordered on both sides by the other variety. For a single season no significant differences were observed among the Delfos combinations, but the Acala combinations differed significantly in most instances. He reported an apparent additive factor for plant competition when averages for the 4 years of the test were considered. On medium fertile soils single-row plots bordered on one side by an unlike variety differed but little from similar plots bordered on both sides by the same variety, and it was suggested that two-row plots be used in trials on such soils.

The results of an experiment to determine the intervarietal competition between varieties of cotton grown on alluvial soil in the Brazos River Valley, near College Station, Texas, are given in this paper, together with an analysis of intervarietal competition from cotton variety test data taken by workers at the U. S. Cotton Field Station, at Greenville, Texas.[4]

## DESIGN AND PROCEDURE

Using data from previous variety tests as a basis for selection, two early-maturing and two late-maturing varieties were chosen for the experiment conducted in the Brazos River Valley in 1940. The early varieties were designated as $E_1$ and $E_2$ and the late varieties as $L_1$ and $L_2$. The greatest opportunity for intervarietal competition should occur when a single row of one variety is bordered on both sides by rows of another variety, as $L_1E_2L_1$. Conversely, there should be no opportunity for intervarietal competition when a single row is bordered on both sides by the same variety, as $E_2E_2E_2$. Therefore, the experiment was designed to determine the effect of intervarietal competition on the middle row of three-row plots when each of the four varieties was grown between border rows of each of the four varieties in the test. Thus, the experiment was adaptable to factorial analysis. The 16 possible combinations of middle rows and border rows in three-row plots were as follows:

Middle row—$E_1$

$E_1E_1E_1$
$E_2E_1E_2$
$L_1E_1L_1$
$L_2E_1L_2$

Middle row—$E_2$

$E_1E_2E_1$
$E_2E_2E_2$
$L_1E_2L_1$
$L_2E_2L_2$

Middle row—$L_1$

$E_1L_1E_1$
$E_2L_1E_2$
$L_1L_1L_1$
$L_2L_1L_2$

Middle row—$L_2$

$E_1L_2E_1$
$E_2L_2E_2$
$L_1L_2L_1$
$L_2L_2L_2$

The three-row plots were randomized within blocks and were replicated six times. The length of plot used was 50 feet. The row width was 40 inches, the width commonly used in commercial plantings in the Brazos River Valley.

[4]The data from the U. S. Cotton Field Station, Greenville, Texas, were made available to the author through the courtesy of D. R. Hooton, Superintendent.

The seeds were planted with an ordinary horse-drawn cotton planter. Good stands were obtained. The usual production methods common to the region were used in thinning, leaving two or three plants per hill at intervals of 8 to 10 inches. Each row of each plot was picked separately and the yield of seed cotton was recorded to an accuracy of 1/10 pound.

The cotton variety tests at the U. S. Cotton Field Station, at Greenville, Texas, from which data were used in this paper, were laid out in four-row plots, 100 feet long, with a minimum of eight replications. The variety tests for 1934, 1936, and 1937 were designed as randomized blocks and the regional variety study for 1936 and 1937 as double restricted latin squares. In this study the regional variety test data were analyzed as randomized blocks.

## RESULTS

### BRAZOS VALLEY EXPERIMENT

Since both of the border rows of each plot were the same variety, the yield of the middle row should measure the net effect of intervarietal competition within a single plot. Table 1 gives the total yield of the six replications of each border-middle row combination and the average border and middle-row variety effect. The effect of a given border treatment will be found by adding the yields of the middle rows of the four plots in each block in which the border treatment occurs. Reference to Table 1 will show that each variety occurs in the middle row once and only once in plots of the same border treatment, thus allowing comparisons between border treatments. The yield of a given variety will be found by adding the yields of the middle row of each plot in which the variety occurs, in which case each border treatment occurs once and only once with the variety.

TABLE 1.—*Yield of middle rows of three-row plots expressed as totals of six replications and averages of 24 plots.*

| Bordered by | Variety | | | | Total | Mean of 24 plots |
|---|---|---|---|---|---|---|
| | $E_1$ | $E_2$ | $L_1$ | $L_2$ | | |
| $E_1$ | 27.1 | 28.7 | 13.9 | 27.7 | 97.4 | 4.06 |
| $E_2$ | 23.0 | 29.4 | 13.5 | 21.9 | 87.8 | 3.66 |
| $L_1$ | 28.4 | 30.5 | 16.8 | 26.2 | 101.9 | 4.25 |
| $L_2$ | 25.4 | 29.3 | 14.7 | 27.5 | 96.9 | 4.04 |
| Total | 103.9 | 117.9 | 58.9 | 103.3 | 384.0 | — |
| Mean of 24 plots | 4.33 | 4.91 | 2.45 | 4.30 | — | — |

It was determined from previous trials that the four varieties used in this experiment differ significantly in yield. Our problem was to determine, under these conditions, the effect of varieties grown as borders on varieties grown between borders. Table 2 gives a gross analysis of these effects and separate comparisons for the main effects of border varieties and middle-row varieties. There was a highly significant border effect showing that there was definite competition among the different border and middle-row variety combinations, or

that the middle rows responded differently to the different border treatments. In the separate border variety comparisons based on a single degree of freedom, the rows bordered by early varieties differed significantly from those bordered by late varieties. There also was a significant difference between the two early border varieties, but there was no difference between the late border varieties. All middle-row variety comparisons gave significant differences. The absence of a significant border×variety interaction indicates a relatively consistent behavior of the four middle-row varieties with respect to the different border treatments.

TABLE 2.—*Analysis of yields of middle rows of three-row plots using four varieties each with four border treatments.*

| Variation due to | D.F. | Sum of squares | Mean square | F |
|---|---|---|---|---|
| Border effect | 3 | 4.3675 | 1.4558 | 5.34* |
| Individual comparisons: | | | | |
| $E_1+E_2$ vs. $L_1+L_2$ | 1 | 1.9267 | 1.9267 | 7.07* |
| $E_1$ vs. $E_2$ | 1 | 1.9200 | 1.9200 | 7.05* |
| $L_1$ vs. $L_2$ | 1 | .5208 | .5208 | 1.91 |
| Middle-row variety | 3 | 82.1550 | 27.3850 | 100.50 |
| Individual comparisons: | | | | |
| $E_1+E_2$ vs. $L_1+L_2$ | 1 | 37.0017 | 37.0017 | 135.79* |
| $E_1$ vs. $E_2$ | 1 | 4.0833 | 4.0833 | 14.99* |
| $L_1$ vs. $L_2$ | 1 | 41.0700 | 41.0700 | 150.72* |
| Border × variety | 9 | 3.3609 | .3734 | 1.37 |
| Blocks | 5 | 9.8150 | 1.9630 | 7.20 |
| Error | 75 | 20.4416 | .2726 | |
| Total | 95 | 120.1400 | | |

*Exceeds P .01.

The results obtained show that there was competition among the four varieties used and it seems reasonable to assume that some bias would have been introduced into an experiment composed of single-row plots of the same varieties.

The design of the experiment was such that comparisons were made between early and late maturity, but it appears that a better comparison would have been between high yield and low yield, since $E_2$, the highest variety in yield, also was the greatest competitor, and $L_1$, the lowest yielding variety, was the poorest competitor. Varieties $E_1$ and $L_2$ were approximately equal both in yield and competitive ability. The experiment suggests a strong association between the yield and the competitive ability of the cotton varieties.

## GREENVILLE EXPERIMENTS

As the varieties used in the Brazos River Valley experiment were chosen arbitrarily to represent somewhat extreme types of plant growth, and as the border rows of each plot were of the same variety, opportunities for intervarietal competition would be greater in such

a test than in one composed of a larger number of varieties representing gradations in yield and plant type. Tests for intervarietal competition may be made in experiments primarily designed for testing yields of a number of varieties provided the plots are composed of three or more rows and are properly randomized.

In 1934, 1936, and 1937 the variety tests at the U. S. Cotton Field Station, at Greenville, Texas, were designed as complete randomized block experiments with four-row plots 100 feet long. The yields of each row of each plot were recorded separately. Individual row data for 1935 were not available. Data from another test grown in 1936 and 1937 and known as the regional variety study also were available for similar analysis. Since the individual plots consisted of four rows, the data were adaptable to a split plot analysis in which the sum of the yields of rows 1 and 4 represented a variety under competition and the sum of rows 2 and 3 represented the variety without competition. In the regular station variety test, 11 varieties were grown for the 3-year period. The regional variety study was made up of 16 varieties representing types from the main regions of the cotton belt.

The essential elements of the analysis of the data from the Greenville experiments are given in Tables 3 and 4. The variance due to *position* measures the over-all effect of the sum of the outside rows compared with the sum of the inside rows without regard to variety. The *variety×position* interaction measures the varietal response to the two possible positions or the intervarietal competition. The *variety×position* interaction was tested by the remainder variance or general error and the *position* effect was tested by the *variety× position* interaction.

The analysis of the data from the regular variety test for the three separate years and for the three years combined is given in Table 3. No significant values were obtained from the 1934 data, a condition probably due to general low yields. In 1936 and 1937 the *variety× position* interactions were significant though barely so at the P.05 level in 1936. The *position* effect was significant at the P.05 level in 1936 and at the P.01 level in 1937. In the combined analysis all of the elements tested gave significant values. The significant *variety× position×years* interaction indicates a difference in the intervarietal competition in the different years.

TABLE 3.—*Analysis of variety tests at Greenville, Texas.*

| Sources | 1934 | | 1936 | | 1937 | | Combined | |
|---|---|---|---|---|---|---|---|---|
| | D.F. | M.S. | D.F. | M.S. | D.F. | M.S. | D.F. | M.S. |
| Years×position | — | — | — | — | — | — | 2 | 4.5480 |
| Position* | 1 | 0.5128 | 1 | 4.5184 | 1 | 24.0796 | 1 | 20.0148 |
| Variety×position | 10 | 0.5959 | 10 | 0.6184 | 10 | 1.7220 | 10 | 1.4493 |
| Variety × position × years | — | — | — | — | — | — | 20 | .7435 |
| Error | 77 | 0.3451 | 77 | 0.3248 | 77 | 0.5722 | 231 | .4140 |
| Total (split plot) | 88 | — | 88 | — | 88 | — | 264 | — |

*Sum of the two outside rows compared with the sum of the two inside rows.

The analysis of the regional variety study, shown in Table 4, gives essentially the same information. The *variety×position* interaction was nonsignificant in 1936, and significant in 1937 and in the combined analysis. The *position* effect was significant in 1936, nonsignificant in 1937, and significant in the combined analysis. The variance for *years×position* and for *variety×position×years* interaction was not significant.

TABLE 4.—*Analysis of regional variety study at Greenville, Texas.*

| Sources | 1936 | | 1937 | | Combined | |
|---|---|---|---|---|---|---|
| | D.F. | M.S. | D.F. | M.S. | D.F. | M.S. |
| Years×position | — | — | — | — | 1 | 0.0508 |
| Position* | 1 | 4.8675 | 1 | 3.5627 | 1 | 8.3794 |
| Variety×position | 15 | 0.4646 | 15 | 1.9992 | 15 | 1.4768 |
| Variety×position×years | — | — | — | — | 15 | 0.9870 |
| Error | 112 | 0.2960 | 112 | 0.9370 | 224 | 0.6165 |
| Total (split plot) | 128 | — | 128 | — | 256 | — |

*Sum of the two outside rows compared with the sum of the two inside rows.

In both experiments there was, as an average of all varieties, a significant difference between the yields of the outside and the inside rows, the difference being in favor of the outside rows. The reason for the generally higher yields of the outside rows is not apparent from the data and no explanation is offered here. Regardless of the general tendency for the outside rows to yield more than the inside rows, there was a significant *variety×position* interaction which is taken as evidence of intervarietal competition.

In these experiments, as in the Brazos River Valley experiments, there was a definite tendency for the higher yielding varieties to be the strongest competitors.

## DISCUSSION

Since evidence of intervarietal competition was found in both the Brazos River Valley and in the Greenville experiments, the question is raised as to whether it was sufficiently great to warrant the use of protective or border rows in varietal test plots. It will be seen in Table 1 that the averages for border effect on yield, while differing significantly, were considerably less variable than the averages for the variety effects. The comparison is even more striking in the Greenville experiments.

The increase in land areas, and the increase in experimental error which usually results, are strong points in favor of the use of single-row plots. It was not possible, from these experiments, to compare the magnitude of the error caused by intervarietal competition, which may be expected in experiments with single-row plots, with the increase in experimental error expected when the plot size is increased from one row to three or more rows. In fact, it is practically

impossible, under the usual field conditions, to design an experiment that will give this information.

It is believed that single-row plots will be the most practical kind for general cotton variety test experiments. The possible exceptions are trials in which the entries are known to differ extremely in yield and in plant type, and trials grown on soils of unusually high fertility. It should be kept in mind that intervarietal competition may occur in any variety test on any soil. However, it is apparent, even in tests where the competition is significant, that its effect usually is not great enough to alter significantly the rank of varietal yields.

## SUMMARY

Four varieties of cotton, two selected for early maturity and two selected for late maturity, were grown in randomized blocks in the Brazos River Valley. The individual plots were designed in such a way that each variety occurring in the middle row of a plot was bordered on both sides by the same variety and each of the three other varieties. The significant values obtained for border effect were attributed to intervarietal competition.

Two sets of data from Greenville, Texas, in which the sum of the yields of the outside rows of four-row plots was compared with the sum of the yields of the inside rows, were analyzed. Significant intervarietal competition, as measured by the *variety×position* interaction, was found. No explanation is offered for the fact that, as an average of all varieties, the outside rows yielded more than the inside rows.

Considering both the Brazos River Valley and the Greenville experiments, the highest yielding varieties generally were the strongest competitors.

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# EFFECT OF SPACING AND SEED SIZE ON YIELD OF POTATOES[1]

B. N. SINGH AND SHANKAR M. WAKANKAR[2]

THE factors of seed size and spacing are of importance in the economy of potato growing; a slight variation in one or both, apart from influencing the yield, affects considerably the initial outlay necessary for planting a required area. While no such work has been reported for India, Bates[3] and Findlay and Sykes[4] have reported that wide spacing reduced total yield and yields of seed and chat potatoes but increased yields and the average size of large ware tubers. Both yield and "net yield" of ware potatoes remained significantly unaffected in their tests. According to these workers, large seed pieces produced the greatest total yield, the greatest "net yield" of ware potatoes, and the most seed. Seed size did not influence the yield of large ware tubers, but the average size of these tubers was greatest from the small seed pieces.

In the absence of local cold storage facilities there is always difficulty in securing the requisite amount of seed potatoes which must be imported from the hills or from certain seed centres. The cost of imported seed is exorbitant during the planting season. The experiment reported here was planned to determine the most suitable spacing and seed size which would be economically suitable and profitable under conditions prevailing at Benares.

## ARRANGEMENT OF EXPERIMENT

The Darjeeling red variety of potato was used for the trials. The design of the experiment was a split-plot one, with spacings as the main treatment and the size of seed as the secondary treatment. The main plots were replicated six times.

The spacings chosen for the experiment were 6, 9, and 12 inches from seed piece to seed piece, 6-inch spacing being the local practice. The seed was sorted into three groups for size, as follows: Small, ¾ to 1 inch in diameter, average weight 15 grams; medium, 1 to 1½ inches in diameter, average weight 30 grams; large, 1½ to 2 inches in diameter, average weight 60 grams. The distance between rows was 24 inches.

The "net size" of the main plots was 30×6 feet and of the sub-plots 30×2 feet. It was necessary to resort to such extremely small one-row sub-plots because of the unavailability of the required amount of large seed potatoes.

The experiment was conducted on a rich sandy loam soil on which a previous crop of manured wheat had been grown. A basal dressing of 30 cart loads per acre of yard manure was applied. Planting was done on Nov. 10, 1941, and the plots harvested on March 17, 1942. Before weighing, the produce from each sub-plot was graded by passing it over a 1¼-inch riddle. Potatoes which remained over

[1]Contribution from the Institute of Agricultural Research, Benares Hindu University, Benares, India. Received for publication April 2, 1943.

[2]Director and Associate, respectively.

[3]BATES, G. H. A study of the factors influencing size of potato tubers. Jour. Agr. Sci., 25:297–313. 1935.

[4]FINDLAY, D. H., and SYKES, E. T. Influence of size of seed and spacing on the yield of King Edward VII potatoes. Emp. Jour. Exp. Agr., 6:253–261. 1938.

this riddle were termed "large" and those which passed through were termed "small."

Four irrigations were given to the crop. The growth of the vines in all the plots was good. The rows planted with large seed pieces appeared more vigorous, apparently because the large seed produced a greater number of shoots per tuber. The shoots from the three seed sizes were equally tall and strong. In the later stages of growth the crop was slightly affected with late blight, *Phytophthora infestans*, but the damage was insignificant.

The analysis of variance used for calculating the standard errors is shown in Table 1.

TABLE 1.—*Form of analysis of variance (sub-plot basis).*

| Variance due to | Degrees of freedom |
|---|---|
| **Whole Plots** | |
| Blocks | 5 |
| Spacing | 2 |
| Error (1) | 10 |
| Total | 17 |
| **Sub-plots** | |
| Seed size | 2 |
| Interaction: Spacing × seed size | 4 |
| Error (2) | 30 |
| Total | 53 |

## RESULTS

The results of the experiment are summarized in Table 2.

Increase in the spacing distance decreased the total yield and the yield of both large and small potatoes, but there was no significant decrease in yield when the spacing distance was increased from 6 to 9 inches. The total yield and the yield of small potatoes was significantly reduced with the wider spacing of 12 inches. There was no significant difference in the yield of large potatoes.

The decrease in the yield of small potatoes with no significant difference in the yield of large potatoes indicated that the size of potatoes, in general, increased as the result of wider spacing. This fact was substantiated by the significant increase in the percentage by weight of large potatoes.

The total yield from large seed was significantly greater than from medium and small seed. The yield from medium seed though higher than from the small seed was not significantly greater. Size of the seed piece did not influence the yield of large potatoes, but the yield of small potatoes was affected considerably. Small seed gave a lower yield of small-sized potatoes when compared with medium-sized seed, and the medium seed gave a lower yield when compared with large seed. Thus, with an increase in the size of seed piece the yield of small potatoes also increased. The percentage by weight of large-sized potatoes decreased significantly with an increase in the size of

seed piece, large seed producing the smallest percentage and small seed the largest percentage of large-sized tubers.

When considering the practical results of an experiment involving a change in seed rate, it is necessary to take into account the quantity of seed used for planting. This is done in the last two columns of Table 2.

TABLE 2.—*Summary of results of experiment, 1941–42.*

| Spacing distance, inches | Total yield, maunds per acre* | Yield of large potatoes over 1¼ inches, maunds per acre | Yield of small potatoes up to 1¼ inches, maunds per acre | Percentage of large potatoes in total yield | Seed potatoes required to plant 1 acre, maunds† | Net yield of potatoes after deducting seed, maunds acre |
|---|---|---|---|---|---|---|
| | | | Small Seed | | | |
| 6...... | 165.6 | 136.1 | 29.5 | 82.5 | 16.6 | 149.0 |
| 9...... | 156.1 | 133.7 | 22.3 | 85.8 | 11.1 | 145.0 |
| 12...... | 121.7 | 115.1 | 6.7 | 94.6 | 8.3 | 113.4 |
| | | | Medium Seed | | | |
| 6...... | 167.3 | 131.2 | 36.2 | 78.4 | 33.2 | 134.1 |
| 9...... | 160.0 | 129.5 | 30.5 | 81.2 | 22.2 | 137.8 |
| 12...... | 134.7 | 120.5 | 14.2 | 89.3 | 16.6 | 118.1 |
| | | | Large Seed | | | |
| 6...... | 171.8 | 127.8 | 44.0 | 74.4 | 66.4 | 105.4 |
| 9...... | 169.7 | 129.1 | 40.6 | 76.2 | 44.4 | 125.4 |
| 12...... | 147.8 | 126.9 | 20.9 | 86.0 | 33.2 | 114.6 |
| | | | Mean Effects of Spacing Distance | | | |
| 6...... | 168.2 | 131.7 | 36.6 | 78.4 | — | 129.5 |
| 9...... | 161.9 | 130.8 | 31.1 | 81.1 | — | 136.1 |
| 12...... | 134.7 | 120.8 | 13.9 | 90.0 | — | 115.4 |
| S.E..... | ±6.91 | ±5.39 | ±2.10 | ±0.36 | — | ±6.91 |
| | | | Mean Effects of Seed Size | | | |
| Small... | 147.8 | 128.3 | 19.5 | 87.6 | — | 135.8 |
| Medium | 154.0 | 127.1 | 27.0 | 82.9 | — | 130.0 |
| Large... | 163.1 | 127.9 | 35.2 | 78.8 | — | 115.1 |
| S.E..... | ±2.52 | ±2.44 | ±1.07 | ±0.35 | — | ±2.52 |
| | | | Spacing × Seed Size | | | |
| S.E..... | ±4.35 | ±4.23 | ±1.85 | ±0.61 | — | ±4.35 |

*1 maund = 82.3 pounds.
†Calculated on basis of 24-inch rows.

From these data it will be seen that after making allowance for the different weights of seed tubers used for each of the treatment, small and medium seed gave significantly larger "net yields" than large seed. The highest net yield, however, was obtained from the small seed. Spacing also influenced the net yield. Increasing the spacing from 6 to 9 inches failed to produce any significant effect, but with

the wider spacing of 12 inches the yield was decidedly reduced. The greatest net yield was obtained with the 9-inch spacing. It will also be noted that with small seed, wide spacing reduced the net yield, but there was no significant difference in yield between 6- and 9-inch spacing. With large seed, however, the yield increased with the 9-inch spacing and decreased again with the 12-inch spacing.

## CONCLUSION

These results suggest that under Benares conditions, on rich sandy loam soil, and with the Darjeeling variety, the use of small seed with 9-inch spacing will be found more economical in potato growing than the other treatments studied.

# SEED PRODUCTION ON GRASS CULMS DETACHED PRIOR TO POLLINATION[1]

Wesley Keller[2]

Pope (11)[3] has shown that barley, *Hordeum vulgare* L., "harvested" prior to flowering produced viable seeds following hand emasculation and pollination, when the detached culms were sustained by distilled water. Harlen and Pope (4) had previously found that barley seeds matured sufficiently to germinate when harvested only 5 days after pollination, and (5) that spikes harvested 3 to 5 days after pollination continued development of the caryopses for at least 8 days if kept moist and in the unthreshed condition. Verret, *et al.* (12) have shown that sugarcane, *Saccharum officinarum* L., would produce viable seeds on canes which were detached prior to pollination and sustained in a 0.05% solution of sulfurous acid. Gruber (3) reported that most of the forage grasses which he investigated would bear viable seeds if harvested 14 days after flowering began. He noted considerable variation between species.

Hermann and Hermann (6) collected seeds of crested wheatgrass, *Agropyron cristatum* (L.) Gaertn., at 3-day intervals beginning 9 days after anther exsertion. None of the seeds harvested 9 days after anther exsertion germinated, either immediately following harvest or during five successive tests conducted at weekly intervals. Seeds harvested 12 days after anther exsertion gave low germination values. Each succeeding period of harvest gave higher germination values than earlier periods, the maximum being reached by ripe seed harvested 36 days after flowering started.

McAlister (10) collected seeds of eight species of grasses at four stages of development, the earliest being 13 to 16 days after full bloom when the seeds were in the pre-milk stage. These pre-milk seeds gave fairly good germination values (70% or more) during the first months of storage. After long periods of storage, however, the decrease in viability was greater in immature than in mature seeds in most instances. He found that hulled seeds of the pre-milk stage, when dry, weighed only 16 to 44% of fully matured seeds.

Although environmental influences encountered by these investigators probably differed, their findings suggest that barley will mature seed in less time, following pollination, than is required by the forage grasses. It was with considerable interest, therefore, that the writer observed, during the winter of 1941–42, that the detached culms of meadow fescue, *Festuca elatior* L., downy chess, *Bromus tectorum* L., and mountain brome, *Bromus carinatus* Hook. and Arn., placed with the cut ends in vials of water prior to flowering produced well-

[1]Contribution of the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, in cooperation with the Utah Agricultural Experiment Station and the Intermountain Forest and Range Experiment Station, U. S. Forest Service, Ogden, Utah. Received for publication March 19, 1943.

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[3]Figures in parenthesis refer to "Literature Cited", p. 623.

developed seeds under bags. A sufficient number of seeds was produced to suggest that in making crosses the female parent may be transported to the pollen source in contrast to the customary procedure of conveying the pollen to the intact female. This is an extension of technic which may frequently be useful in practice. The present study was undertaken to determine the feasibility of the method under field conditions.

## MATERIALS AND METHODS

The grass species used were those available which were near the flowering stage on June 30, 1942, when the experiment was initiated. The species are listed in Table 1. Culms were severed 2 or 3 inches above the crown and inserted into pint fruit jars through nail holes in the lids. The purpose of the lids was to reduce water loss from the jars by evaporation. As a further means of reducing evaporation, the jars were partly submerged in the soil on the shady side of a row of grass. This row of grass provided a source of pollen for those species which naturally cross pollinated by wind. None of the inflorescences were emasculated, therefore self pollen probably functioned for those species which are naturally selfed. The culms, standing in water, with no leaves removed, were held upright by securing them to a vertical wire stake with a small identification tag. No further attention was given this material until 28 days later when the ripened inflorescences were transferred to paper bags. At this time most of the jars contained only a small quantity of brackish water; others were dry. A few inflorescences showed evidence of some shattering or mechanical injury. Some normal inflorescences from intact culms were also harvested to permit comparison of seed size and germination. After drying thoroughly, the material was hand threshed and cleaned, the seeds counted and weighed. Seeds from detached culms of some species threshed free of the glumes in which case the glumes were removed from similiar seeds produced on intact culms in order to obtain valid weight comparisons. Germination values were determined by planting all of the seeds produced, up to 100, in a silty clay loam soil on a heated greenhouse bench. The seeds were covered lightly (1/8 to 1/4 inch) and the soil kept moist.

## RESULTS

### SEED PRODUCTION

Nine of the 11 species included in the test produced seeds, as indicated in Table 1. With few exceptions the seed yields were considered to be good. Shattering reduced the yield from *Agropyron ciliare* and *A. cristatum*, also from one lot each of *A. semicostatum* and *Festuca elatior*. The best seed yields were obtained from *F. elatior* which gave almost 100 seeds per panicle, and from some of the lots of *A. trachycaulum*, *A. semicostatum*, and *Bromus inermis*, each of which approached or exceeded 50 seeds per spike or panicle. Only one panicle of *Bromus carinatus* was included in the study. It gave a low yield of seed. Culms of *A. ciliare* (C), *A. trachycaulum* (M), and *Hordeum jubatum* (W) which were detached before the inflorescences had completely emerged from the boot all gave good seed yields. *Phalaris arundinacea* and *Phleum pratense* failed to produce any seeds. The pollen source of these two species was very limited and flowering had almost been completed when this study started. Seeds

TABLE 1.—*Number of seeds and weight and germination of seeds produced on detached and intact culms.**

| Species and stage of development of inflorescences when detached from the parent plant | Number of culms, or spikelets | Total seeds | Relative weight | Per cent germination | Relative germination |
|---|---|---|---|---|---|
| *Agropyron ciliare* (Trin.) Franch. | | | | | |
| Normal (B) | — | — | 100 | 80 | 100 |
| (A) Ready to flower | 2† | 4 | 83 | 100 | 125 |
| (C) Half out of boot | 5 | 22 | 55 | 27 | 34 |
| *A. cristatum* (L.) Gaertn., Normal (E) | — | — | 100 | 45 | 100 |
| (D) Ready to flower | 1 | 7 | 67 | 29 | 64 |
| *A. semicostatum* (Steud.) Nees., Normal (FK) | — | — | 100 | 76 | 100 |
| (G) Flowering had started | 3 | 11 | 48 | 64 | 84 |
| (H) Same; large seeds | 22 | 47 | 67 | 60 | 79 |
| (I) Same; medium size seeds | 12 | 33 | 18 | 12 | 16 |
| (J) Same; smallest seeds | 16 | 24 | 9 | 0 | 0 |
| *A. trachycaulum* (Link) Malte, Normal (L) | — | — | 100 | 97 | 100 |
| (M) Half out of boot | 77 | 206 | 71 | 100 | 103 |
| A-785; Normal (N) | — | — | 100 | 86 | 100 |
| (O) Flowering had started | 58 | 90 | 71 | 86 | 100 |
| (P) Ready to flower | 45 | 34 | 53 | 79 | 92 |
| *Bromus carinatus* Hook. and Arn., Normal (Q) | — | — | 100 | 71 | 100 |
| (R) Half out of boot | 1 | 7 | 71 | 57 | 80 |
| *B. inermis* Leyss., Normal (S) | — | — | 100 | 94 | 100 |
| (T) Ready to flower | 2 | 124 | 30 | 33 | 35 |
| (U) Ready to flower | 1 | 52 | 45 | 22 | 23 |
| *Hordeum jubatum* L. Normal (V) | — | — | 100 | 96 | 100 |
| (W) Half out of boot | 3 | 91 | 40 | 88 | 92 |
| *Festuca elatior* L. Normal (Z) | — | — | 100 | 56 | 100 |
| (X) Ready to flower | 2 | 190 | 67 | 53 | 95 |
| (Y) Just out of boot | 2 | 190 | 59 | 57 | 102 |
| *Phalaris tuberosa* L. ready to flower | 2 | 28 | — | 96 | — |
| *P. arundinacea* L. ready to flower | 2 | 0 | — | — | — |
| *Phleum pratense* L. ready to flower | 2 | 0 | — | — | — |

*Capital letters in parentheses identify each lot in Fig. 1. Normal refers to mature seeds harvested from intact culms.

†In this column numbers 1 to 3 designate culms, whereas higher numbers refer to spikelets. There was evidence of shattering or other mechanical injury in lots designated by the following capital letters: A, C, D, G and X.

might have resulted with a more abundant pollen supply. Therefore, the data presented are not considered sufficient proof that these species are incapable of seed production by the method in question.

The number of seeds produced per culm is not considered a reliable indicator of the potential seed-producing capacity of the individual

species, since the number of inflorescences used was small. The principal point of interest is that culms detached from the parent plant and placed in water under the conditions of this experiment were capable of maturing seeds. Representative seeds from each lot are illustrated in Fig. 1.

## RELATIVE SEED WEIGHT

All the seeds produced on detached culms were lighter in weight than those which matured naturally. Most species had some detached culms which gave seeds one half or more the weight of normal seeds. Several exceptions occurred, however. Three spikes of *Agropyron semicostatum* yielded seeds of readily distinguished sizes, the weights being 67, 16, and 9% of normal, respectively. *Bromus inermis* seeds from detached culms were only 30 and 45% of normal and those of *Hordeum jubatum* 40% of normal. Seeds of *A. semicostatum*, *Bromus carinatus*, and *B. inermis* from detached culms threshed free of the glumes. In order to determine comparative weights the glumes were removed from normal seeds of these species. In the remaining species the glumes adhered to the caryopses, and were not removed to determine relative weights. These values therefore are relative weights of caryopses plus glumes. Since the glumes on detached culms appear normally developed (Fig. 1), the values given in Table 1 are probably higher than they would be if determined from caryopses alone.

## GERMINATION

Seeds matured on intact culms required less time to germinate than those from detached culms. Examination of the seedbed one week after planting revealed good germination from most of the seeds matured normally, but little germination from those matured on detached culms. After 12 days, however, the chief difference was in size of seedlings and after 18 days size difference between species were much greater than those between treatments. Percentage germination was based on apparently normal seedlings which emerged through ⅛ to ¼ inch of moist soil. The germination test was started 3½ months after the seeds were harvested, and final counts reported in Table 1 were taken 18 days later.

In general, germination of seeds from detached culms was only slightly below that of seeds from intact culms. *Bromus inermis*, *Agropyron ciliare*, and the smaller seeds of *A. semicostatum* were exceptions. Normally matured seeds of *A. cristatum* and *Festuca elatior* gave low germination values, for which no explanation is apparent. A low germination value was obtained for *A. ciliare* seeds from a culm detached when the spike was half out of the boot. This can be partly explained by examination of typical seeds in Fig. 1 (C), compared with normal seeds (B). The dark color of the latter, in contrast to the sterile appearance of the former, is a direct reflection of the extent to which the caryopses had developed in each. It is apparent from this that most of the relative weight reported for "C" in Table 1 is due to an apparently normal development of the glumes on detached culms.

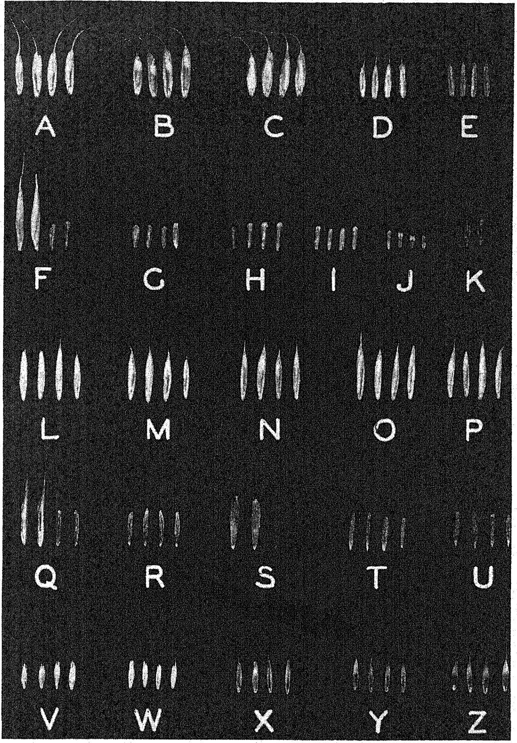


FIG. 1.—Grass seeds produced on detached and intact culms. A–C, *Agropyron ciliare;* A, detached when ready to flower; B, normal; C, detached when half out of boot. D–E, *Agropyron cristatum;* D, detached when ready to flower; E, normal. F–K, *Agropyron semicostatum;* F, normal; G–J, detached when flowering had started; G, plant A. H to J, plant B; H, largest seeds; I, medium size seeds; J, smallest seeds; K, normal. L–P, *Agropyron trachycaulum;* L, normal; M, detached when half out of boot; N–P, strain A-785; N, normal; O, detached when flowering had started; P, detached when ready to flower. Q–R, *Bromus carinatus;* Q, normal; R, detached when half out of boot. S–U, *Bromus inermis*, S; normal; T & U, detached when ready to flower. V–W, *Hordeum jubatum;* V, normal; W, detached when half out of boot. X–Z, *Festuca elatior;* X, detached when ready to flower; Y, detached when just out of boot; Z, normal.

## DISCUSSION

Preliminary trials have demonstrated that several species of forage grasses will mature viable seeds on culms which have been detached prior to pollination. This method of seed production does not alter the necessity for emasculation if controlled hybrids are desired. The maximum amount of seed which can be produced on detached culms will require further investigation. The environmental forces encountered will probably always constitute an important element in the production of seeds by detached culms under field conditions. Flowering and early seed development of the species studied normally occur at Logan, Utah, during the period of June 10 to July 15. Temperatures for 23 years show an average daily gain of approximately one-third degree F, increasing from 78° F on June 10 to 90° F by July 15. If high temperatures are injurious to seed setting, it appears that the earlier the pollinating can be done the better. Maximum temperatures for 1942 showed wide fluctuations during June, owing chiefly to storms. This was followed by higher than normal temperatures from July 2 to 14. July 4 to 7, inclusive, maximum temperatures ranged between 93° and 96° F. It was during this period that the plants under study were either flowering or in early post-pollination stages. The average daily minimum temperature increased from approximately 50° F on June 10 to 60° F by July 15, while the minimum daily temperature for 1942 fluctuated in a manner closely resembling that of the 1942 daily maximum. It is clear that the plants studied in 1942 withstood considerably higher than average temperatures. The experiment was conducted at the end of the flowering period when temperatures were excessively high. It is probable, therefore, that as far as temperatures are concerned, seed production on detached culms would be possible in most seasons. No records are available regarding wind movement, but the area generally is characterized by Alter (1) as having light to moderate winds, a high percentage of sunshiny days, and low relative humidity, all favoring rapid evaporation.

According to Jenkins (8), corn tassels survive and shed viable pollen longer if the water in which they are placed contains sodium bisulfite in the proportion of 1 to 2,000 (0.05%). Brandes and Sartoris (2) reviewed the various cane breeding technics, including that of Verret, *et al.* (12) referred to in the introduction. They report that sugar cane arrows detached prior to flowering will mature viable seeds if the canes are sustained in a solution of sulfurous acid and phosphoric acid, each 1 to 1,000. Canes placed in this solution actually grew and remained fresh a month, but in water alone they would survive only a day or two. This is a remarkable demonstration of the role of chemicals in plant breeding. On the other hand, Hitchcock and Zimmerman (7) tested 51 chemicals, including sulfurous acid, in an attempt to prolong the life of cut flowers without significant results. Laurie (9) noted that copper had a bactericidal action, but its use failed to add materially to the life of cut flowers. Seed production in grasses by post-harvest pollination might be materially improved by the use of chemicals. The conflicting results obtained on

other species of plants indicate that this may require experimental determination for each species of grass.

Pope (11) cut about 1 inch from the lower end of his barley culms several times during the course of his investigation. It is possible that this treatment might be beneficial to grass. Maintaining fresh water in the jars may prove beneficial. For practical use the detached culms should not remain in the field for a month, as in the present study. In periods of extremely hot or windy weather, some advantage may be gained by removing the detached culms to a protected area as soon as pollination has been completed.

## SUMMARY

Under field conditions at Logan, Utah, the following species of forage grasses will mature viable seeds on culms detached prior to pollination and placed with cut ends in tap water in proximity to appropriate pollen sources; *Agropyron ciliare*, *A. cristatum*, *A. trachycaulum*, *Bromus carinatus*, *B. inermis*, *Hordeum jubatum*, *Festuca elatior*, and *Phalaris tuberosa*. Viable seeds were also produced on culms of *A. semicostatum* which had already begun to flower when they were detached. *Phalaris arundinacea* and *Phleum pratense* failed to produce any seeds by post-harvest pollination, but from the limited scope of the study little significance should be attached to negative results.

Most lots of seeds from detached culms weighed from 40 to 83% of those matured on intact culms. Seeds from detached culms of *A. ciliare*, *A. trachycaulum*, *H. jubatum*, and *F. elatior* germinated approximately as well as those from the control lots of the same species. Germination was fairly high for other species with the exception of *B. inermis* which gave values of 25 and 35%.

Grass seed production on culms detached prior to pollination constitutes an extension of technic which may be useful in practical breeding operations.

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# GROWTH AND DECAY OF THE TRANSIENT (NONCAMBIAL) ROOTS OF ALFALFA[1]

Fred Reuel Jones[2]

In the course of a study of the mycorrhizal fungus in the roots of legumes the writer in 1924 (4)[3] recorded an extensive dying of the ends of alfalfa rootlets in midsummer at a time when they were making little growth. Subsequent observations have confirmed the opinion that this occurs regularly to a greater or less extent in the vicinity of Madison, Wis., even with the most favorable climatic conditions and cutting treatment. During the recent dry summers a well-irrigated nursery has been used in which root dying has been found to take place even more severely than in some of the drier fields. Among a large number of clones of plants of diverse growth character and three or four years of age in this irrigated nursery, it appeared that those which were more dormant in the summer lost more rootlets than those which were less dormant, and all lost rootlets earlier than alfalfa in some of the fields on nearby farms. Finally, among inbred lines grown in the irrigated nursery and selected for wilt resistance and winter hardiness, a few declined in vigor after two or three years of growth with no apparent cause other than a poorly developed root system. From this it appeared that there might be important differences among plants in their responses to root-destroying agencies.

With this background, in 1941 a systematic examination of the roots of alfalfa was begun to trace the development of this decay. Since no study of seasonal elongation of rootlets in old alfalfa plants has been published, it was necessary to supply this in rough outline also, and this soon involved, in turn, examination of the morphology of the roots involved. The results obtained in this examination of rootlet decay in relation to the growth and morphology of the roots affected is presented in the following pages. The determination of the organisms causing decay remains to be completed.

## REVIEW OF LITERATURE

No explicit description of seasonal growth and decay of alfalfa rootlets has been found in the extensive literature of root growth in that plant. In the extensive data on root growth recorded in studies of root storage in relation to management practices and to winterkilling, only the large storage roots have been considered, in comparison with which the rootlets furnish very little weight if collected. It may be inferred from the following descriptions that root storage and root elongation in old plants may not be strictly contemporaneous developments and may even be fundamentally incompatible.

[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, in cooperation with the Wisconsin Agricultural Experiment Station, Madison, Wis. Received for publication March 26, 1943.

[2]Senior Pathologist, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils and Agricultural Engineering.

[3]Figures in parenthesis refer to "Literature Cited", p. 634.

The rootlets of old plants appear to have been examined most critically by those who were chiefly interested in them as the origin of nodules, and, in fact, the closest approach to a partial statement of the spring growth and summer decay of rootlets in alfalfa and some other legumes appears to have been made by those interested primarily in the often observed decay of nodules in summer. Fred, *et al.* (2, page 190) in a discussion of the normal life of the nodule state, "In other words, the formation of new nodules or the development of new lobes upon existing nodules closely parallels the development of new rootlets." But even in the subsequent discussion of premature destruction of nodules they do not note a situation often found in alfalfa in which the nodules decay along with the rootlets to which they are attached. Thus, the parallel between nodule formation and decay and rootlet formation and decay is not completed.

Wilson (10, Figs. 2 and 3), illustrating the disappearance of nodules in consequence of experimental cutting treatment in white clover, apparently illustrates the disappearance of the rootlets to which the nodules are attached along with the nodules, though he does not mention this association.

The branching habit of the mature alfalfa root system has been correctly illustrated by Weaver (9, Figs. 101–102), branches from the taproot reaching only to the fourth in numbered order. While Eames and MacDaniels have stated (1, page 133) that, ". . . in some woody species a considerable proportion of fibrous rootlets contain only primary growth", no examination of these branches in alfalfa appears to have been made to determine if any of them consistently remain primary in structure, a matter of first importance in the pathology of these roots. Several studies of the morphology of alfalfa roots reviewed and extended by Simonds (6) and summarized by Hayward (3) are concerned chiefly with the seedling, and with the large roots that are of interest as storage organs. The development and maturity of the peripheral rootlets in plants several years of age does not appear to have been examined.

## PERMANENT AND TRANSIENT ROOTS OF ALFALFA

In the examination of the root systems of alfalfa it was soon found desirable to distinguish at any time, if possible by macroscopic examination, between smaller rootlets which had begun secondary thickening and those which were still primary in structure. The importance of this distinction came from the observed fact that the decay described in detail later was entirely of primary root structure. The result of this decay in its extreme development in old plants was to strip the root system at the end of the summer of nearly all of the rootlets which had no well-developed secondary growth leaving comparatively few roots, but leaving the remaining rootlets little harmed and capable of developing new branches in the fall and spring. The more complete removal of the noncambial roots from old plants made such plants more convenient for the observation of the year-round behavior of roots; therefore, the following observations have been made on plants 2 years old or older unless otherwise stated.

Among the smaller roots it is obviously impossible to distinguish those which are primary in structure from those which have some secondary thickening on the basis of size. Rootlets which are primary in structure differ among themselves greatly in diameter (Fig. 1, A and B) and sometimes have a vascular cylinder which occupies but a

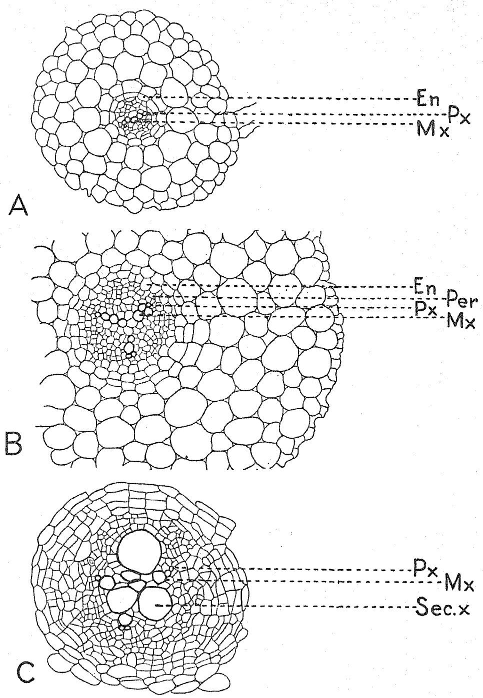


FIG. 1.—A large and a small rootlet of primary structure compared with a small root with early secondary development. A, transection of a small rootlet of primary structure. The metaxylem band across the vascular cylinder is completed. B, a large rootlet of primary structure. Metaxylem has not yet appeared at the center of the root. C, transection of a rootlet beginning secondary thickening rather weakly in summer. The two largest vessels appear to be secondary in origin, possibly the third large vessel also. The phellem is in an early stage of development. en, endodermis; mx, metaxylem; px, protoxylem; per, pericycle; sec. x., secondary xylem. $\times 170$.

twentieth of the cross sectional area. Thus rootlets which have shed their primary cortex with its four to six layers of large cells between the endodermis and the piliferous layer and have begun secondary

thickening are smaller in diameter than before cambial activity began. Thus, to determine internal structure, the sectioning of many rootlets was necessary. The usual method of imbedding rootlets in paraffin for sectioning requires so much time and results in so much shrinkage that the rootlets were usually sectioned immediately, imbedded in bundles in 5% agar. The agar blocks were sectioned readily as soon as cool, and even better after they had been placed in 70% alcohol for a day or more. If root hairs were not abundant, the root sections floated out of the agar and could be collected for staining and mounting. The remaining agar blocks were imbedded in paraffin and sectioned later in the usual way, if necessary.

Secondary thickening in rootlets is initiated by the cambium and, subsequently a phellogen, derived from the pericycle, begins to cut off cork also. In the smallest rootlets the cambial strands are at first inconspicuous, the number of cells produced from them are few, and thus the earliest vessels formed from the cambium are not always easily distinguished from the last vessels formed in the centripetal maturity of the metaxylem (Fig. 1, C). This is especially true in rootlets from a clay subsoil where vessels produced from both sources are few and of great diameter with consequent disarrangement of the surrounding cells. It is often true in rootlets produced in cool weather when metaxylem appears to mature over a long period. Thus, a precise determination of the inception of cambial activity is often very difficult. Fortunately, the subsequent development of the phellogen which is necessary for the preservation of the root can be seen easily, and in doubtful cases this is the most useful evidence of secondary growth. Among the old plants under study it was found that very few of the young rootlets produced in a season have an active cambium. Thereupon search was made for the condition that determined why some young rootlets terminated axial enlargement upon the maturation of the primary tissues, while others continued to grow as a result of cambial activity. A search in the primary structure of rootlets for indication of their future potentialities has thus far been in vain. The rootlets that become permanent are usually among the largest, and the largest are usually triarch rather than diarch, though some of the very smallest are triarch. No strict relationship between the size of a rootlet or the number of its primary vascular bundles and its future development became apparent. The clue to the probable development of a rootlet was finally found in its position in the root system.

The branching habit of the alfalfa root system is well illustrated by Weaver (9, Figs. 101 and 102). The taproot is shown with branches differing greatly in length and size. The largest of these branch, and these in turn, until the fourth branches numbered in order from the taproot are reached. No branches beyond this fourth order shown by Weaver have been found in the plants examined. When branching occurs to the fourth order, the first two branches are found with much secondary thickening from cambiums which appear to have developed early in the growth of the root. These branches with secondary thickening together with the taproot are conveniently called the permanent root system of the plant, or the cambial roots.

From this permanent root system arise many branches, usually short, but sometimes quite long, which may in turn have a few short branches. These branches originate in the first instance in the usual manner opposite protoxylem points in the primary roots, but they may die and be succeeded again and again by others from the same place of emergence after the secondary tissues have been added to the permanent roots. These rootlets and their branches rarely develop cambiums, at least no complete phellogen, and thus they appear unable to survive indefinitely. There appears to be no established term distinguishing such shortlived roots from the permanent roots. Warning (8) has designated as transient roots in parsnip rootlets that may have an even shorter duration than those in alfalfa, and may in part have a dissimilar origin; but provisionally this term may serve. Thus, these shortlived rootlets are designated transient roots, or the noncambial root system. The positional relation between the permanent and the transient roots is shown in Fig. 2.

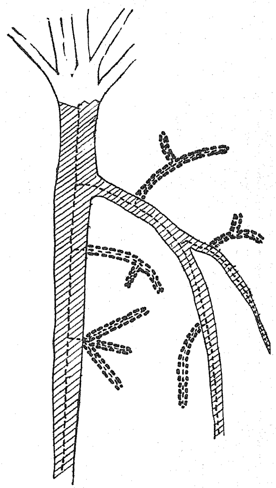

FIG. 2.—Diagramatic representation of a longi-section of the mature root system of alfalfa showing branching habit and distinguishing permanent and transient roots. Cross-hatching represents permanent structures, crown, and permanent roots (////). Broken lines represent transient structures, vascular cylinder of roots and primary cortex of roots.

Additions to the permanent root system are made frequently in old plants from rootlets which grow more rapidly than their neighbors, and which develop cambiums. Sometimes several rootlets near each other go through the early stages of the formation of permanent roots, developing cambiums that decline in activity before many vessels have been matured. Among these a strict classification of cambial and noncambial roots cannot be made. However, the instances in which the classification of rootlets cannot be made clearly have not occurred often enough to impair the utility of the distinction between the permanent and the transient roots. The same classification can be made almost equally well in sweet clover, and probably in other biennial plants. In addition to the roots shown by Weaver in the figures cited above, plants may develop an adventitious root system from the crown when the stems have become well overgrown with rootlike tissues, and when soil moisture is maintained about the

crown. The adventitious roots develop like branches from the taproot, or, if this is lost, like new taproots.

## SEASONAL GROWTH OF TRANSIENT ROOTS

The plants used most frequently in the tracing of root growth were from the nursery to which reference has been made. Roots were also obtained from fields on farms for comparison at critical seasons. The estimate of root elongation from time to time was made by successive records of the length of rootlets found on similar locations in the root system, and by the color of the roots and the distance of the mycorrhizal fungus from root ends at some seasons. The records of mitotic figures used by Stuckey (7) to indicate growth in her study of the growth of grass roots did not appear to be practicable in this instance. The opinions reached should be regarded only as a rough survey from which only the outstanding features of growth habit may be outlined.

In the spring very few transient roots are found emerging and little elongation takes place prior to top growth. The period of most vigorous root growth begins following the inception of vigorous top growth early in May, and continues until, or almost until, the plants begin to flower. The precise time at which this grand period of root growth begins to decline is often difficult to determine because in most years the soil becomes dry early in June, and this condition may itself retard root growth. In 1942 frequent showers in June kept the surface so moist that roots often lacked root hairs as in water cultures, and even under this condition it appeared that the rate of root growth began to decline early in June. By the Middle of June root growth was greatly lessened, and in plants left uncut till the first of July there was little evidence of the emergence of new roots, and those which were not killed as described later did not appear to be growing. From this time on through the summer very few new rootlets appeared, and surviving transient roots grew slowly if at all.

A second, lesser period of growth begins about the middle of September when moisture is abundant and extends into October, declining with the colder weather or the killing of tops by frost. In this period growth is found chiefly in the adventitious roots or in roots near the surface of the soil, but not in roots 2 feet or more deep as in spring growth. No growth has been detected in winter. In the late autumn of 1941 some rows of alfalfa were heavily mulched before the ground froze that roots might be kept unfrozen for observation during the winter. Even in the spring when etiolated shoots formed, no root elongation was detected. It may be noted that, while root growth is described above as occurring in two periods, it is possible and perhaps equally useful to regard these periods as essentially one which is interrupted by winter.

Root growth in the summer has been far more inactive than anticipated. In the dry season of 1941 it was suspected that the drought was restricting root growth and recovery after the first cutting. Therefore on July 3 a portion of some rows that had been cut 10 days earlier was freely irrigated and a part of the irrigated tract was

heavily mulched to reduce soil temperature. The irrigation did not greatly stimulate top growth, and root growth was not much increased even where the mulch was used.

Since transient roots grow rapidly when the first crop is developing fast in the spring, it was anticipated that a corresponding growth of roots would be found accompanying the second crop. This anticipated correlation between root and top growth has not been found. Apparently, in this locality, the second crop is produced upon the surviving part of the transient root system produced largely in the growth of the first crop with very little addition developed along with the second crop.

Parenthetically it is noted that on this meagre summer growth of rootlets few nodules are found, though in a previous study (5) a high soil temperature was found to favor nodule formation. A partial explanation of the failure of nodule formation may be found in the position of the mycorrhizal fungus in those rootlets at this time. Wipf and Cooper (12) have described the development of nodules from disomatic cells located near the endodermis, which is the region in which the mycorrhizal fungus advances filling cells with "arbuscles". In summer this fungus advances close to many root ends and in so doing may occupy the disomatic cells before the infection thread of rhizobium reaches them, or, at least, early enough to prevent them from becoming meristematic after they are infected. When this occurs, the invading bacteria would apparently become pathological agents contributing to the destruction of the outer cells of the root as described by Fred, *et al.* (2, page 823).

It is interesting to note further that in the transient roots the metaxylem usually produces some vessels of a size and character corresponding to the dominant type produced at the same time by the cambium. In summer when large vessels are being laid down by the cambium in the cambial roots, the last metaxylem vessels produced in the maturing primary root are of great diameter also, even though it appears that the latter large vessels do not join directly with the large ones in the main root, but rather communicate with them through a group of small vessels at the base of the rootlet. Metaxylem vessels produced in the autumn are small as in the main root, and it is not certain that differentiation proceeds to completion in many of them until spring. Thus, the metaxylem of the transient roots has similarities in morphology with the contemporaneous secondary xylem in the permanent roots.

In contrast with their behavior in old plants, the roots of seedlings or of cuttings set in the ground in the spring do not show in their first year the extreme periodicity in growth described above. Here root growth is most active in spring and again in fall, but there is moderate growth during the entire summer, especially if the tops are not cut back. While it is perhaps premature to suggest reasons for the differences in behavior in root growth between seedlings and old plants, it may be noted that Stuckey (7) suggests that in grasses the production of new roots may be inhibited by developing flower primordia. Wilton and Roberts (11) also state from a study of several species that the flowering stem is characterized by a less active

cambium than nonflowering stems. While these authors refer to a stem cambium only, it is possible that root procambiums develop similarly.

## SEASONAL DECAY OF TRANSIENT ROOTS

The following account of the decay of transient roots in alfalfa is compiled from observations made in selected locations where it appeared that the injury observed came initially from microorganisms in the soil rather than from drought or other unfavorable soil conditions. Judgment may easily have been in error in making the selection, and therefore conclusions lack the support which should come from a more precise knowledge of the etiology of the injury. The important fact for the present is that these rootlets do die in great numbers, and at different times in different locations.

The earliest indication of root deterioration in spring is usually the greenish yellow discoloration of the cortex following the invasion by the mycorrhizal fungus. This appears in the latter part of May. Early in June a browning of the cortex of rootlets begins to appear, some of which may be due to the mycorrhizal fungus, but some of which may be found independently of this fungus in the underlying cells. Species of Fusarium have been isolated from such rootlets, but their pathogenicity has not been determined. The yellowing may begin in small areas and spread until the entire rootlet is discolored nearly to the region of elongation. By the middle of June this browning is abundant, and the ends of some of the rootlets are decayed. No branching of the rootlet back of the decayed region has been observed to carry on the extension of the rootlet. Rootlets with discolored cortex and decayed ends die back to their origin in a permanent root. New roots may arise at the base of dead roots, and these may die in turn until at the end of the summer clusters of three or even more dead rootlets are found. Rootlets do appear to respond by branching to physical injury. Sometimes when the ends of rootlets are destroyed by insect feeding, a branch emerges back of the elongating region, and the rootlet resumes growth without much delay.

The extent of this decay in rootlets differs greatly in different locations. In the clonal nursery it may be proceeding so rapidly in mid-June that the transient root system is no longer increasing in extent, and by the end of June the transient roots formed in spring may have comparatively few living root ends. From mid-July through August the transient roots furnish little absorbing surface for the support of foliage, and in fact the second crop is very small in this nursery. The decay has been found undiminished in severity in the subsoil 3 feet from the surface. In clones of highly dormant Ladak alfalfa destruction appears more complete than in clones of more actively growing Grimm. In fact, the transient roots through which presumably water absorption largely takes place are nearly absent for so long in the more dormant clones that it seems possible that this condition may lead to their deterioration and death.

From observations in farm fields, it is evident that root decay does not everywhere begin as early or proceed as rapidly as in the irrigated nursery. The field with the best preserved roots found in

1942 had produced an excellent second crop. The fact that the mycorrhizal fungus was found close to the ends of the roots in the summer in this field indicated that they were growing very slowly, but the root ends were living. On the basis of a few local observations it appears that a vigorous second crop may be evidence of the preservation of a large part of the root system that developed with the first crop. It is hoped that a more extended examination of this relation can be made later.

## DISCUSSION OF RESULTS

The distinction drawn in this paper between the noncambial or transient rootlets and the cambial or permanent roots makes it easier to emphasize in studies of root diseases that the two kinds of roots not only have fundamentally different diseases, but that they have fundamentally different abilities to react to disease. Moreover the transient roots react differently to their fungus invaders as they pass through different stages of their growth cycle until as growth becomes very slow, it may be impracticable to distinguish precisely between disease and the disintegration which must follow inactivity. That plants may survive for a long period in the year with very little transient root system has become apparent. But the growth of the plant while such rootlets are few is clearly small in quantity and different in character from that while such rootlets are abundant. For economical crop production, it certainly appears necessary that most of the transient rootlets developed in spring should be retained until late in the summer. In an exploration of the extent to which this is possible, the degree to which the decay of transient rootlets is due to conditions that may be properly called disease—and disease that can be controlled—must be determined. It is possible that low productivity in second and third cuttings and reduced yields in stands several years of age may be found associated with the death of transient roots early in the summer.

## SUMMARY

The dying of alfalfa rootlets in summer at Madison, Wis., which has been mentioned briefly by the writer previously, has been reexamined as a phase of the obvious, but apparently undescribed, root succession in this plant.

Rootlets die following a browning and shrinking of the primary cortex in which the mycorrhizal fungus may or may not be present, and following a soft decay of the ends of rootlets. The agents causing decay are not determined.

Two kinds of roots are distinguished in alfalfa on the basis of morphology, duration, and function. They are described as the permanent or the cambial roots and the transient or noncambial roots. The permanent roots, serving for transport and storage, consist almost entirely of secondary growth from a cambium and a phellogen, and are limited to the taproot, a few of its branches, and a few of the branches from the first branches. The transient roots arise in the usual manner from the permanent roots, but they develop little or

no cambium and no phellem. When these rootlets die they may be replaced by new transient rootlets emerging near their bases.

The rate of transient root growth and regeneration differs greatly during the growing season, and this periodicity of growth is much more marked after the first year. The period of most vigorous root growth begins in May after the stems have begun rapid elongation, and reaches its maximum about the first of June. Growth declines by the middle of June, and by the first of July reaches a minimum that persists through the summer. In the latter part of September roots near the surface of the soil become active in growth and continue thus, but with lessened vigor as cold increases in October. No appreciable growth has been found in winter even when the soil is protected from freezing.

Root deterioration begins in late May or early June, and increases rapidly from the middle to the end of June. Where decay is severe, the development of rootlets in July and August appears to be largely inhibited by the decay of root ends almost as soon as they emerge. The severity of the decay differs in different fields, and in plants with different habits of growth. It seems possible that the early decay of transient roots limits to some extent the growth of the second crop.

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# NOTES

## FAILURE OF VETCH TO EXCRETE NITROGEN FROM THE NODULES WHEN GROWN IN ASSOCIATION WITH NITROGEN-DEFICIENT CITRUS SEEDLINGS[1]

IN connection with studies of nitrogen gains and losses in California soils, an experiment was set up in pot culture to determine whether nitrogen-starved citrus seedlings would show any benefit when grown in association with vetch. The thought was to determine whether nitrogen excretion from root nodules might occur under the climatic conditions prevailing in this region. Though the original findings by Virtanen, *et al.*[2] have been substantiated by Wilson,[3] the latter has concluded that nitrogen excretion by legume nodules probably depends on climatic conditions which favor nitrogen fixation rate, on the one hand, but limit photosynthetic rate on the other. Under such conditions fixed nitrogen is not utilized in growth as rapidly as it is formed and thence may accumulate in and be excreted by the nodule.

Sweet orange seedlings were transplanted into a series of 18 2-gallon pots filled with a uniformly mixed loam soil of low nitrogen content, on August 23, 1937. The plants were allowed to grow in the greenhouse until February 9, 1938, by which time all plants had ceased growing and were very yellow owing to extreme nitrogen deficiency. Sweet orange seedlings in such a state will become green and resume growth within 10 days if given nitrogen but without nitrogen will remain essentially dormant for months.

On the aforementioned date, inoculated purple vetch was planted in 8 of the 18 plots. The vetch germinated well and the cultures were kept in the greenhouse until April 15, 1938, by which time the vetch had made substantial growth. There was no sign of greening or growth of the citrus seedlings in the vetch pots, however.

In order to alter the climatic conditions, all of the pots were taken out of doors on April 15. At the end of 1½ months of further growth out of doors there was no change in the appearance of the citrus seedlings in the vetch pots as compared with the controls, hence the experiment was discontinued.

Pictures were taken of the tops and roots of representative pots and the dry weights (Table 1) of the tops of all plant material in each pot obtained. Pictures showing the appearance of the tops of the seedlings with and without vetch, the nodulation of the vetch roots, and the intertwining of the vetch and citrus roots are presented in Fig. 1.

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[1]Paper No. 486, University of California Citrus Experiment Station, Riverside, Calif.

[2]VIRTANEN, ARTTURI ILMARI, HANSEN, SYNNÖVE VON, and LAINE, TAUNO. Investigations on the root nodule bacteria of leguminous plants. XIX. Influence of various factors on the excretion of nitrogenous compounds from the nodules. Jour. Agr. Sci., 27:332–348. 1937.

[3]WILSON, PERRY W. The biochemistry of symbiotic nitrogen fixation. Univ. Wisconsin Press, Madison, Wis., 142–162. 1940.

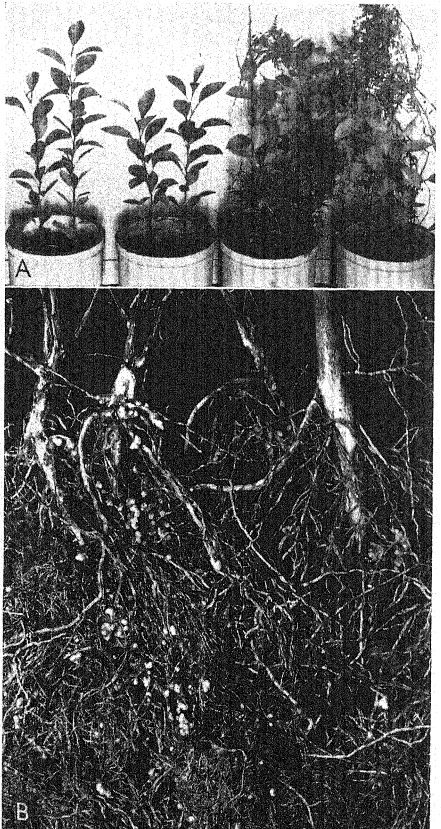


FIG. 1.—A, tops of nitrogen-starved citrus seedlings growing alone and in association with vetch; B, roots of citrus seedling (extreme right), and of three vetch plants. Note nodulation of vetch and intertwining of roots of the citrus and vetch.

TABLE 1.—*Dry weight of citrus seedlings grown with and without vetch.*

| Pot No. | Oven-dry weight of tops, grams | | | |
|---|---|---|---|---|
| | Citrus per pot | Average | Vetch per pot | Average |
| 1 | 17.7 | — | 10.7 | — |
| 2 | 9.0 | — | 13.0 | — |
| 3 | 8.3 | — | 20.4 | — |
| 4 | 12.4 | 10.6 | 15.8 | 19.5 |
| 5 | 8.1 | — | 21.6 | — |
| 6 | 7.2 | — | 32.2 | — |
| 7 | 10.1 | — | 16.6 | — |
| 8 | 11.9 | — | 25.7 | — |
| 9 | 14.3 | — | — | — |
| 10 | 17.3 | — | — | — |
| 11 | 9.6 | — | — | — |
| 12 | 13.7 | — | — | — |
| 13 | 13.8 | 13.1 | — | — |
| 14 | 9.3 | — | — | — |
| 15 | 19.9 | — | — | — |
| 16 | 13.6 | — | — | — |
| 17 | 10.0 | — | — | — |
| 18 | 9.8 | — | — | — |

It is apparent from both the dry weight data and the failure of citrus leaves in the vetch pots to show green that no benefit accrued to the citrus seedlings from the associated growth with vetch; hence it can be asserted that no significant excretion of root nodule nitrogen occurred.—H. D. CHAPMAN, *University of California Citrus Experiment Station, Riverside, California.*

## MULTIPLYING PEANUT HYBRIDS BY VEGETATIVE PROPAGATION

HYBRIDIZATION of peanuts, *Arachis hypogea*, is a tedious task. The buds must be emasculated at night for pollination the following morning. Approximately 10 minutes is required for each complete pollination. The average fruit set from hand-pollinated flowers is seldom more than 60%, with an average of 1.5 seeds per fruit. Virginia type peanut plants spaced 12 inches apart in 3-foot rows will produce from 50 to 100 seed. Thus, 10 to 20 hand-pollinated $F_1$ seed are required to produce the 1,024 $F_2$ seed theoretically necessary to obtain all genetic combinations if five factors are segregating. Hull[1] and Higgins, *et al.*,[2] have reported enormous amounts of segregation occurring in peanut hybrids which is supported by the senior author's observations on hybrids of small-podded and large-podded types. Hull reports evidence of duplicate genes and polyploidy. It appears that most of the desired characteristics in peanuts are

[1]HULL, FRED H. Inheritance of rest period of seeds and certain other characters in the peanut. Fla. Agr. Exp. Sta. Bul. 314. 1937.

[2]HIGGINS, B. B., HOLLEY, K. T., PICKETT, T. A., and WHEELER, C. D. I. Peanut breeding and characteristics of some new strains. Ga. Agr. Exp. Sta. Bul. 213:3–11. 1941.

governed by several to many genes making a large segregating ($F_2$) population necessary for success in peanut breeding work.

In January 1942, 40 vegetative cuttings were made from greenhouse-grown plants. After treating with a hormone solution and placing in moist sand, all cuttings formed good roots in 10 days. These cuttings were grown to maturity in the greenhouse. Only fair plant development was obtained since the cuttings were allowed to become pot-bound in 3-inch pots before transplanting to the ground bed.

A small field test was conducted in 1942 to compare the yielding properties of vegetative cuttings as compared with plants from seed. Three standard peanut types were chosen, *viz.*, large bunch (N. C. Sel. 32 of Va. Bunch), medium runner (a farmer's stock known locally as Knight's or Martin County Runner), and small bunch (Spanish 2B, a large Spanish selection). Cuttings were made from greenhouse-grown plants. Lateral branch cuttings and main stem cuttings were kept separate throughout the test. At the time of transplanting into the field (May 22) seed of each variety were planted as checks. A randomized split-pot design of six replications of 10 plant plots was used. The three sources of plants (main stem, lateral branch, and seed) made up the sub-plots, while the three strains comprised the whole plots.

The results (Table 1) show no significant difference between the two sources of cuttings. The yield of plants from seed was significantly less than that for plants from main stems but not so for plants from lateral branches. Time of planting has a marked influence on peanut yields so if the seed had been planted 2 weeks earlier it is reasonable to expect plants from this source might have produced as much as those from main stem cuttings. When the sources of plants are considered by individual strains, some interesting differences are observed. The late-maturing Virginia bunch shows plants from seed produced significantly less than plants from either of the other two sources. On the other hand, the early-maturing Spanish strain produced approximately equally from the three plant sources. N. C. 32 and Martin County runner show significant differences in yield for plants from lateral branches and those from main stem cuttings.

TABLE 1.—*Yield of peanut strains from vegetative cuttings and from seed, yield of unshelled nuts adjusted for missing plants given as pounds per acre.*

| Strain | Lateral branch | Main stem | Seed | Av. for strain* |
|---|---|---|---|---|
| N. C. Sel. 32 | 1,237.8 | 1,514.4 | 890.0 | 1,193.9 |
| Martin Co. Runner | 1,002.5 | 1,281.6 | 1,173.9 | 1,132.4 |
| Spanish 2B | 1,127.6 | 1,026.7 | 1,028.1 | 1,101.0 |
| Av. for source of plants* | 1,122.3 | 1,274.6 | 1,030.0 | |

*Adjusted for missing plants on basis of whole plot error variance.

There is an inherent factor present in the Virginia bunch and runner strains which presumably may account for the differential yield of the two sources of cuttings. The main stem in these two strains never

bears flowers, i.e., only lateral branches bear flowers. On the other hand, Spanish plants bear flowers on both the main stem and lateral branches. The difference in flowering habit was noticeable very early in the plants from cuttings. Plants from main stem cuttings of N. C. 32 and Martin County runner did not flower on the main stem but developed lateral flower-bearing branches. Plants from lateral branch cuttings of these two strains started or continued to flower on the original branch now serving as a main stem. The most striking difference occurred in the runner strain. The lateral branch cuttings, even though forced to serve as a main stem, again became prostrate and developed as a lateral branch on a normal plant. This geotropic response caused the complete development of the lateral cutting plant to be to one side of the root attachment. The main stem developed in all respects as a normal plant putting out new runner laterals and fruiting only on these branches. All plants attained approximately normal amount of growth and branching. The development of typical plants of the Spanish strains are shown in Fig. 1 as the plants were dug in September.

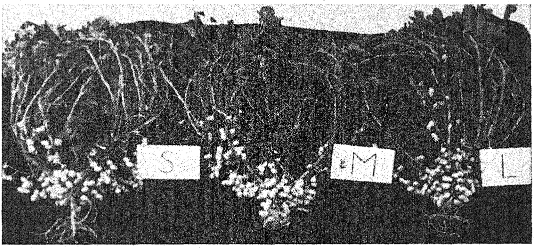


FIG. 1.—Typical Spanish plants after digging in September. S, from seed; M, from main stem; L from lateral branch cutting.

The cutting technic makes it possible to test $F_1$ peanut hybrids in replicated yield trials if desired. Immer[3] has recently pointed out the advantages of early testing of hybrid populations in self-pollinated crops. It is possible to gain this information for peanut hybrids with a relatively small amount of actual crossing. Three cuttings can be made from a vigorous 6-week-old plant. From plants thus obtained a second set of cuttings could be made in two or three months time. Thus, in one winter season, one $F_1$ plant could be multiplied 20 to 50 or more plants by spring planting time. In addition to permitting yield trials on the $F_1$ plants the amount of $F_2$ seed produced would be vastly increased. Special tests such as chemical analyses which destroy the seed might be made without unduly reducing the size of the $F_2$ population.—PAUL H. HARVEY and E. F. SCHULTZ, JR., *North Carolina Agricultural Experiment Station, Raleigh, N. C.*

[3]IMMER, F. R. Relation between yielding ability and homozygosis in barley crosses. Jour. Amer. Soc. Agron., 33:200–206. 1941.

## BOOK REVIEWS

### FUNDAMENTALS OF SOIL SCIENCE

*By C. E. Millar and L. M. Turk. New York: John Wiley & Sons, Inc. London: Chapman & Hall, Ltd. XI + 462 pages, illus. 1943. $3.75.*

ACCORDING to the authors, this volume, prepared as a college textbook and as a reference book for anyone interested in soils and their management, has a fourfold object, "To give the reader the opportunity to become familiar with soils as natural units or entities and with their inherent characteristics, to develop in the student an understanding of the significance of fundamental soil properties, to set forth basic relationships between soils and plants, and to give the reader an understanding of the principles involved in the use of proved soil-management practices."

A critical examination convinces the reviewer that the authors have ably accomplished all four of these objectives. Technical enough for the average student in soils, its simplicity and directness of statement will also appeal to the non-student who wants to know something of the why and wherefore of many of our soil-management practices.

The scope of the book is suggested by its 19 chapter headings which include soil development, classification, physical and chemical properties, reaction and its regulation, moisture, biology, organic matter and various manures, plant nutrition and nutrients, fertilizers and their use, and productivity ratings. The last five chapters are given over to more specialized subjects, such as agriculture in arid regions, irrigation, fruit and lawn soils and the soil resources of the United States. Lists of student questions are given under many of the sub-headings. After the text a valuable nine-page glossary of terms is given, followed by what appears to be an excellent index.

The book can be unhesitatingly recommended to anyone interested in gaining a comprehensive knowledge of the science of soils. (R. C. C.)

### WORLD TRADE IN AGRICULTURAL PRODUCTS

*By Henry C. Taylor and Anne Dewees Taylor. New York: Macmillan Company. XVIII + 286 pages, illus. 1943. $3.50.*

THE authors, Director of the Farm Foundation of Chicago and independent research student in the history of agricultural economics, respectively, bring to bear on this study of agricultural products in their economic aspects, a broad background of training, travel, and research in this field. The book presents an authoritative world picture of "the underlying motives and far-reaching effects of national trade policies, of imperial preferences, of international trade agreements, and of all sorts of production and trade restrictions, also relationships between standards of living and widespread controls that force agriculture, industry, and commerce into uneconomic channels". According to the authors the study was prepared as a contribution to the factual background needed for an appraisal of the problems that face the builders of a world social struc-

ture designed to provide the conditions essential to the progress of civilization.

The work was given incentive and extension through the senior author's membership on the Permanent Committee of the International Institute of Agriculture in Rome. This Institute published in Rome in 1940 the very extensive "World Trade in Agricultural Products: Its Growth; Its Crisis; and the New Trade Policies". Since very few copies of this study, or of a 96-page summary made later, ever reached the United States, the present volume has been prepared largely from this more extensive work.

Each of the major agricultural products is discussed separately, and includes a world map showing the net trade of the principal importing and exporting countries, charts of volume and gold value of world exports, and statistical tables. A separate chapter discusses government policies.

This work and the collaboration of the U. S. Dept. of Agriculture in various ways has, without doubt given us the most authoritative book available on this vitally important subject. It can be recommended without reservation. (R. C. C.)

## EXPLORING TOMORROW'S AGRICULTURE: COOPERATIVE GROUP FARMING—A PRACTICAL PROGRAM OF RURAL REHABILITATION

*By Joseph W. Eaton, with foreword by M. L. Wilson. New York and London: Harper & Brothers, XVI + 255 pages, illus. 1943. $2.75.*

IN THIS volume the author, who is Director of Research of the Rural Settlement Institute, presents what he considers a possible solution to a very important rural problem, one which will undoubtedly become more acute after the war. This problem in his own words is, "How can farmers in general, and low-income farmers in particular, get an adequate and secure income to live by, a stimulating and important type of work to live for, a pleasant and well-integrated community to live in, a happy family and friends to live with and enough leisure to just live?"

The author thinks the solution lies in the cooperative group farm and the book is an intimate study of this movement. It first deals with the theory of cooperative group farming, including such topics as the ten criteria which are used as a standard of rural rehabilitation, the tasks and obstacles involved, resettlement, large-scale and family farming, and an outline of a possible program.

The second section gives some analysis of the cooperative corporation farms of the Farm Security Administration, as to their layouts, objectives and philosophy, establishment, membership and program, management, measure of success, and future possibilities. The last section deals with other types of cooperative group farms, both in this country and abroad.

This book is a thought-provoking one which will undoubtedly help to shape our future thinking in an important sociological field. Anyone in the least interested in the position of the farmer in the post-war world should read it. (R. C. C.)

# AGRONOMIC AFFAIRS

## LITERATURE ON THE MINOR ELEMENTS

THE Chilean Nitrate Educational Bureau, Inc., announces publication of the fourth supplement to the third edition of the "Bibliography of References to the Literature on the Minor Elements and Their Relation to Plant and Animal Nutrition."

The first edition of this bibliography was published in August 1935, the second in November 1936, and the third, the last complete edition, in February, 1939. Subsequently, the first supplement was published in April 1940, the second in April 1941, and the third in May 1942.

The fourth supplement contains about 94 pages and 690 abstracts, which include 110 crops and 30 elements. There are 887 authors listed. Complete indices are provided, including an element index, a botanical index, and an author index which includes the names of all authors listed in the various abstracts. Also, at the suggestion of Dr. W. O. Robinson of the U. S. Dept. of Agriculture, a number of elements which previously have been classified individually, now are grouped together under the heading "Rare Earths".

For further information about this new supplement, write to the Chilean Nitrate Educational Bureau, 120 Broadway, New York City.

## AGRICULTURAL SPECIALISTS AND AGRICULTURAL AIDS SOUGHT FOR FEDERAL SERVICE

PERSONS who have had agricultural experience or education are being sought for Federal Civilian War Service. Agricultural Specialists in extension, research, program planning, and conservation are paid from $2,600 to $6,500 a year (plus overtime pay); however, appointments to positions paying over $4,600 will be few. Applicants must have had experience or education, or a combination of the two, involving some scientific or technical aspect of agricultural production or distribution, or some other scientific or professional phase of agriculture such as rural planning, farm finance, and rural education. Experience may have been gained in such agriculture activities as extension, research, college teaching, program planning, conservation, and vocational agriculture teaching. Some positions require farming experience.

Agricultural Aids are needed to assist in semitechnical laboratory or field work. Two to four years of technical experience in agriculture or the equivalent in agricultural study in college is required. The positions pay from $1,970 to $2,433.

Applications should be filed with the Civil Service Commission, Washington, D. C. There are no age limits and no written examinations. Further information and application forms may be obtained at first- and second-class post offices, or from the Commission's Regional or Washington offices.

## NEWS ITEMS

According to Science, Dr. George D. Scarseth has been appointed Head of the Department of Agronomy, Purdue University, Lafayette, Ind., effective July 1. Doctor Scarseth, who has been serving as Professor of Soils and as Soil Chemist at the Purdue University Experiment Station since 1937, succeeds Professor A. T. Wiancko who is retiring on June 30 after serving for 40 years. Professor Wiancko is a charter member of the American Society of Agronomy.

—A—

Eric W. Stark of the Texas State Forest Service has been appointed Associate Professor of Forestry in the School of Agriculture and Associate in Forestry and Conservation in the Experiment Station, Purdue University, Lafayette, Ind. He will carry on research and teaching in wood properties and wood utilization.

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The Annual meeting of the Canadian Seed Growers' Association was held at St. Dunstan's College, Charlottetown, P. E. I., June 22 and 23.

—A—

Professor Dale A. Hinkle of the Department of Agronomy, New Mexico College of Agriculture and Mechanic Arts, State College, N. M., has been granted leave of absence for the duration of the war to accept a commission as Lieutenant (J. G.) in the Navy.

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Doctor W. B. Ellett, Head of the Department of Agricultural Chemistry at the Virginia Agricultural Experiment Station, Blacksburg, Va., died on May 12 after an illness of almost four months.

—A—

E. F. Henry, Assistant Agronomist assigned to soil survey work at the Virginia Agricultural Experiment Station, has resigned to accept a position in the Navy as a Lieutenant (J. G.). Mr. Henry's place has been filled by J. H. Petro, a graduate of Ohio State University who was formerly employed by the Soil Conservation Service in their survey program.

—A—

Doctor A. L. Grizzard, Associate Agronomist in charge of the pasture investigations work in the Agronomy Department, Virginia Agricultural Experiment Station, resigned on May 1 to accept a position with the office of Inter-American Affairs and is stationed in El Salvador.

—A—

J. D. Guthrie, in charge of the experimental farm of the Virginia Agricultural Experiment Station and also in charge of the plant breeding work in the state, resigned on June 10 to accept a position with the office of Inter-American Affairs. He is stationed in Bolivia. The position vacated by Mr. Guthrie has been filled by the appoint-

ment of Dr. Malcolm H. McVicker. Doctor McVicker received his undergraduate training at the University of Illinois and received his Ph.D. from Ohio State University in 1939. Previous to reporting to Blacksburg on his new assignment he was employed by the Farm Security Administration.

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Doctor Firman E. Bear, Chairman of the sub-committee on Nitrogen Utilization on Haylands and Pastures of the national joint committee on Nitrogen Utilization, has announced the personnel of the sub-committee as follows: R. B. Becker, Florida Agricultural Experiment Station, Gainesville, Fla. (Florida, Georgia, Alabama); C. B. Bender, New Jersey Agricultural Experiment Station, New Brunswick, N. J. (New Jersey, Delaware, Maryland); B. A. Brown, Connecticut Agricultural Experiment Station, Storrs, Conn. (New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut); R. W. Cummings, North Carolina Agricultural Experiment Station, Raleigh, N. C. (North Carolina, South Carolina, Virginia); D. R. Dodd, Ohio Agricultural Experiment Station, Wooster, Ohio (Ohio, Indiana, Michigan, Wisconsin, West Virginia); D. S. Fink, Cornell University, Ithaca, N. Y. (New York, Pennsylvania, Maine); H. J. Harper, Oklahoma Agricultural Experiment Station, Stillwater, Okla. (Oklahoma, Kansas, Nebraska, Texas); M. A. Hein, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C. (Washington, Oregon, California); H. H. Lush, National Fertilizer Association, 616 Investment Building, Washington, D. C. (Louisiana, Mississippi, Tennessee, Kentucky); and H. H. Tucker, Educational and Research Bureau, 50 West Broad St., Columbus, Ohio (Illinois, Iowa, Missouri, Arkansas, North Dakota, South Dakota). Each member will undertake to study the work that is being done in the states following his name. Doctor D. S. Fink will summarize the work in this field before Section IV of the Soil Science Society in Cincinnati in November. It is also expected that the sub-committee will convene during the Cincinnati meetings to consider the 1944 program.

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## EFFICIENCY STUDIES OF TYPES OF DESIGN WITH SMALL GRAIN YIELD TRIALS[1]


J. H. TORRIE, H. L. SHANDS, AND B. D. LEITH[2]


PROBLEMS concerned with varietal testing are of prime interest to agronomists in relation to the determination of the adaptation and yield of named varieties and new hybrids for the purpose of making recommendations to farmers. Experiment stations commonly have available a large number of selections for yield tests. Many of these can be eliminated by deficiencies that can be detected by observation, yet many remain that require yield trials to determine their productive capacities. It is important that as much information be secured as possible from the use of small plots. During the past few years considerable interest has been focused on the lattice designs developed by Yates (18)[3] as a means of increasing precision. Many experiment stations test varieties simultaneously in rod rows and in larger field plots. The question then arises as to whether the relative response of the varieties is the same for both methods of testing. Some investigators harvest quadrats in place of the entire plot. The principal questions are, first, how many quadrats per plot are necessary to give the desired precision, and second, how do the responses of the varieties as measured by quadrats compare with those determined on the entire plot basis. In this paper data obtained during the past 6 years by the Wisconsin Agricultural Experiment Station at Madison are used as a study of the points mentioned above.

### MATERIALS AND METHODS

The data used in this study consist of the grain yields from the wheat, oats, and barley rod-row and 1/60-acre plot experiments conducted by the Department of Agronomy at the University Hill Farms, Madison, Wis., during the period 1937 to


[1]Contribution from the Department of Agronomy, Wisconsin Agricultural Experiment Station, Madison, Wis. Published with the approval of the Director. Paper No. 185. Received for publication March 26, 1943.



[2]Assistant Professor, Associate Professor, and Professor of Agronomy, respectively.


The authors wish to thank Dr. Churchill Eisenhart, Statistician, Wisconsin Agricultural Experiment Station, for his counsel in selecting the methods of statistical analysis used and for his assistance in the preparation of the manuscript; and Dr. R. G. Shands for making available to the authors the data for the spring wheat rod row tests for the years 1937 to 1942, inclusive.


[3]Figures in parenthesis refer to "Literature Cited", p. 660.

1942. Data obtained from the oat rod-row nurseries at the Hancock and Marshfield branch experiment stations during the period 1938 to 1941 are also included. The 1938–39 winter wheat trial is not included in the comparison of the lattice and randomized complete block designs because of severe differential winter injury in one replication.

The technic used for the rod-row nurseries will be described briefly. All tests were replicated four times. The shape of an individual replicate block was made as nearly square as possible. This was accomplished by arranging the varieties within a replication in two tiers with the exceptions of the 1938 oat test and one of the 1942 oat tests with single rows for which three and one tiers were used, respectively. Each of the rod-row plots consisted of three rows, 18 feet long and 1 foot apart, with the exception of the last oat test listed in Table 1 for which single-row plots were used. At harvest the middle 16 feet of the center row was taken for yield. Since 1938 the lattice design has been used for the oats, barley, and winter wheat nurseries.

The more promising varieties were tested in 1/60-acre plots, with the exception of the spring grains during 1937 and 1938 when 1/80-acre plots were used. The 1/60- and 1/80-acre plots are referred to as field plots in this paper. During the 5-year period of 1937 to 1941, four quadrats were harvested from each plot. The quadrats were taken at random with the restriction that each quarter of the field plot be sampled. The quadrats were 4×4 feet square. The field plots and rod-row nurseries were usually located on different fields.

## COMPARISON OF LATTICE AND RANDOMIZED COMPLETE BLOCK DESIGNS

Lattice designs, formerly called pseudo-factorial or quasi-factorial, were first described by Yates (18). Later Yates (19) reported a more accurate method of analysis by which inter-block information is recovered. The purposes of the lattice designs are to provide a more accurate method than randomized complete blocks when a large number of varieties are to be tested and to retain as far as possible equal accuracy of comparison between every pair of varieties in the test.

A review of the literature on lattice designs shows that they are more precise in most comparisons than randomized complete blocks. Yates (18) and Goulden (8), using data from uniformity trials without recovery of inter-block information, found the lattice designs more precise than randomized complete blocks. Yates in two studies reported gains of 26% and 57%, while Goulden concluded from a study of 26 sets of data that the incomplete block designs were 20% to 25% more precise on the average than randomized complete blocks. Later studies by Cox, *et al*, (6), Cochran (5), and Zuber (20), using Iowa corn data, in which inter-block information is recovered, indicated substantial gains for the lattice designs. Cochran (4) reported on the results of six wheat experiments conducted by L. R. Waldron at Fargo, N. D., with the number of varieties ranging from 49 to 169. Two showed no gain, one a gain of 2% while the other three showed gains of 39%, 45%, and 156%. Cochran (5) from a study of 20 triple lattice experiments conducted with corn in Iowa calculated that three replicates of the triple lattice design were somewhat more

accurate on the average than five replicates of the type of randomized block design used, but that somewhat smaller increases could be expected with a more compact replication. Zuber (20), using data from a corn yield uniformity trial in Iowa, reported an average increase in precision of 36% over randomized complete blocks for the following incomplete block designs, lattice, triple lattice, balanced lattice, and lattice square.

The results from 22 lattice designs used on the present investigations are shown in Table 1. The data are arranged according to crop, year, and location of the tests. The data include the variance of the

TABLE 1.—*Relative efficiency of the lattice design, with and without recovery of inter-block information, compared with the randomized complete block design, based on rod-row data from several Wisconsin experiment stations.*

| Crop and location | Year | Design | Variance of the difference between two varietal means, bu. | | | Mean yield per acre, bu. | Relative precision factor | |
|---|---|---|---|---|---|---|---|---|
| | | | R.C.B.* | R. | I. | | R. | I. |
| Oats, Madison | 1938 | 9×10 | 21.47 | 19.86 | 23.81 | 44.0 | 108 | 90 |
| | 1939 | 7×7 | 33.32 | 31.11 | 35.16 | 59.3 | 107 | 95 |
| | 1940 | 8×8 | 51.19 | 50.38 | 58.45 | 73.6 | 102 | 88 |
| | 1941 | 8×8 | 46.92 | 37.37 | 39.38 | 60.6 | 126 | 119 |
| | 1942 | 7×7 | 79.78 | 79.75 | 101.23 | 77.7 | 100 | 79 |
| | 1942 | 7×7 | 60.83 | 55.10 | 61.37 | 79.9 | 109 | 92 |
| Mean........ | | | | | | | 109 | 94 |
| Oats, Hancock | 1938 | 4×5 | 3.52 | 3.24 | 3.88 | 17.8 | 109 | 91 |
| | 1939 | 4×5 | 5.04 | 5.04 | 6.92 | 20.3 | 100 | 73 |
| | 1940 | 4×5 | 8.28 | 7.75 | 9.37 | 38.2 | 107 | 88 |
| | 1941 | 4×5 | 17.04 | 14.93 | 17.45 | 24.3 | 114 | 98 |
| Oats, Marshfield | 1938 | 4×5 | 10.08 | 10.08 | 13.21 | 17.6 | 100 | 76 |
| | 1939 | 4×5 | 19.09 | 17.61 | 22.22 | 41.5 | 108 | 86 |
| | 1940 | 4×5 | 27.02 | 25.90 | 32.07 | 40.1 | 104 | 84 |
| | 1941 | 4×5 | 36.45 | 35.68 | 45.25 | 69.6 | 102 | 81 |
| Mean........ | | | | | | | 106 | 85 |
| Barley, Madison | 1938 | 8×8 | 19.61 | 19.17 | 22.57 | 42.1 | 101 | 87 |
| | 1939 | 6×7 | 9.60 | 8.90 | 9.58 | 42.0 | 108 | 100 |
| | 1940 | 6×7 | 20.21 | 11.66 | 12.18 | 45.3 | 173 | 166 |
| | 1941 | 7×7 | 17.52 | 17.51 | 22.13 | 25.3 | 100 | 79 |
| | 1942 | 8×8 | 27.61 | 27.33 | 31.99 | 40.9 | 101 | 86 |
| Mean........ | | | | | | | 118 | 104 |
| Winter wheat, Madison | 1940 | 7×7 | 18.18 | 15.18 | 17.90 | 38.3 | 112 | 102 |
| | 1941 | 7×7 | 17.52 | 17.51 | 22.13 | 25.3 | 100 | 79 |
| | 1942 | 7×7 | 12.29 | 12.29 | 15.39 | 39.7 | 100 | 80 |
| Mean........ | | | | | | | 104 | 87 |
| Mean of all tests..... | | | | | | | 109 | 92 |

*R.C.B. = Randomized complete blocks; R = Inter-block information recovered; I = Inter-block information ignored.

difference between two varietal means for the randomized complete block and the lattice, with and without recovery of inter-block information, as well as the relative precision of the lattice in respect to the randomized complete block. The variance of the difference between two varietal means ($s^2_{\bar{d}}$) was calculated by the method described by Cox, *et al.* (6). For the randomized complete block $s^2_{\bar{d}}$ is $\frac{2s^2}{r}$. For the lattice design without recovery of inter-block information it is $\left[\frac{(2s^2)}{r}\right] \cdot \left[\frac{(k+3)}{(k+1)}\right]$, and for the lattice design with recovery of inter-block information it is $\left[\frac{2s^2}{r(k+1)}\right] \cdot \left[\frac{4w}{w+w'} + (k-1)\right]$. In the preceding formulae $s^2$ is the error mean square, r the number of replications, k the number of varieties in an incomplete block, $w = \frac{1}{s^2}$ and $w' = \frac{3}{4B - s^2}$, where $s^2$ and B are, respectively, the error and block mean squares. In the above formulae for $s^2_{\bar{d}}$ for the lattice design the expressions given are the mean variances of differences between two varietal means. The actual values differ somewhat from these depending upon whether the two varieties to be compared are in the same or different incomplete blocks.

The variance of a difference between two varietal means ($s^2_{\bar{d}}$) has a definite relation to the minimum difference required for significance between two means. The minimum difference required for significance between varietal means at the .05 or .01 levels is t at .05 or .01 for error degrees of freedom times $\sqrt{s^2_{\bar{d}}}$. The relative precision factor for the lattice was obtained by dividing the $s^2_{\bar{d}}$ for randomized complete blocks by that for the lattice design. If a precision factor of 125% is obtained, it means that four replicates in a lattice design are as efficient as five in randomized complete block trials.

The average gain in precision of the 22 lattice designs with recovery of inter-block information is only 9%, while without recovery of inter-block information there is an average loss of 8% in precision. Only one test, that for barley in 1940, showed a large increase in precision, namely, 73%. Eighteen of the 22 experiments gave an increase of less than 10%, while 11 showed less than 5% gain. There was no pronounced difference in gain in relative precision of the lattice designs for the different crops. The small increases in precision obtained indicate that the variation between incomplete blocks within a replication is essentially the same as the variation between the individual plots within an incomplete block. In other words, there are few or no real differences in productivity between the incomplete blocks within a replication. The conclusion should not be drawn from the above data that lattice designs under all conditions could be expected to give only a slight gain in precision on the average over randomized complete blocks. Where there is a sizeable difference between incomplete blocks, the lattice designs will give considerable increase in precision.

The data presented in this paper, when considered in relation to the literature reviewed, indicate that lattice designs under some conditions will give large gains in precision whereas in other instances the gains may be small. This indicates that each experiment station will probably have to determine locally what gains may be expected from the use of lattice designs as compared to randomized complete blocks, rather than to depend entirely upon the results obtained at some other station. The question may be raised as to the advisability of using a lattice design in place of the randomized complete block where experience over a period of years shows that the gain in precision is small, as has been the case at Madison. As pointed out by Cochran (4), to a person who is familiar with lattice designs, the extra work involved in the statistical analysis of the data is a small fraction of the total. Another worthwhile point is that occasionally a really large gain in precision may be obtained as evidenced by the 73% gain for the 1940 barley trial at Madison. This increase in precision in terms of the minimum difference required for significance between two varietal means amounts to 2.14 bushels per acre. The minimum differences required for significance with the randomized complete block and the lattice design with recovery of inter-block information are, respectively, 8.89 and 6.75 bushels per acre. Moreover, with the recovery of inter-block information the lattice design cannot be less precise than the randomized complete block. This would indicate that the experimenter who is willing to take a little more trouble in statistical analysis has nothing to lose and everything to gain. The use of lattice designs in situations where missing values are of frequent occurrence may be undesirable owing to the greater complexity of the analysis when values are missing.

## COMPARISONS OF ROD ROWS, FIELD PLOTS, AND QUADRAT SAMPLES OF FIELD PLOTS

In varietal testing of cereal crops the question is often raised as to whether the varieties react differentially for grain yields under differend methods of testing. The results of several investigations indicate that a good agreement between methods exists when quadrats harvested from drill-sown plots are compared with the entire plot for yield of grain. The number and type of quadrats recommended by the different investigators varies considerably. Kiesselbach (11) recommended 20 systematically distributed quadrats each 32 inches square. Arny and Garber (1) in fertilizer trials with spring wheat found that nine rod rows harvested from 1/10-acre plots gave results practically as accurate as harvesting the entire plot. Arny and Steinmetz (2) from a study of 1/10-acre cereal plots at several locations in Minnesota recommended 4 to 5 square-yard quadrats for plots where the stand is uniform and up to 10 where the stand is not uniform. Clapham (3) and Kalamkar (10) found that it was necessary to harvest 30- and 36-meter lengths, respectively, from 1/40-acre plots to obtain a sampling error of approximately 5%. Michels and Schwendiman (14) recommended that for cereal crops 12 to 18 square yards be harvested from 1/40-acre plots to provide yields comparable to those of entire plots.

The literature comparing the results obtained from small nursery plots such as rod rows and larger drilled plots show, in general, excellent agreement. Kiesselbach (12) reports good agreement between winter wheat strains sown in rod rows and in larger drilled plots. Hayes, *et al.* (9) from a comparison of the yield of 16 highly selected varieties of spring wheat grown in 1/40-acre plots and in rod rows using different rates of seeding found the best agreement when rod rods were seeded at a heavy rate. Klages (13) compared the yields of small grains in rod rows and drilled plots over a 3- to 4-year period by means of correlation and comparison of rank. In general, his results showed good agreement using the two types of plots. Smith and Myers (16) found good agreement between the yields of 12 timothy varieties grown in rod rows and 1/50-acre plots. Frankel (7) from a 5-year study of three to eight wheat varieties found a close agreement between the yield of samples from large drilled plots and square yard plots. Smith (15) compared yields of nine wheat varieties in 1/100-acre plots harvested by sampling with those obtained from square yard plots. He reported a close agreement using the two methods.

In order to determine if the varieties reacted similarly for the different methods of testing yielding ability, the variety-type of plot interaction was tested by comparing its mean square with that of error by the F test. A significant F value would indicate that certain of the varieties responded differently under the two methods of test. In order to determine which varieties reacted differently, the following formula was used in the comparison of the quadrats and 1/60-acre plots with the rod rows: $d=\bar{D}\pm t\sqrt{\frac{s^2}{r}\cdot\frac{2(N-1)}{N}}$, where d = difference required for significance between means of the two methods for a variety, $\bar{D}$ = average difference between the two methods, $s^2$ = error mean square, r = number of replications, N = number of varieties, and t = .01 level of "t" for the degrees of freedom of the error mean square.

Since the difference required for significance is dependent upon both the difference within a variety for the two methods and the average difference for all varieties between methods, $\frac{N-1}{N}$ was used in the above formula. The proof is as follows:

$$d_1-\bar{D}=d_1-\frac{d_1+d_2+\cdots\cdots+d_N}{N}$$

$$=\frac{(N-1)d_1-\sum_{i=2}^{N} di}{N},$$

where $d_1$ is the difference between the two methods of testing for any one of the varieties. Since for independent variables $d_1$, $d_2$ ---- $d_N$, with common variance $\sigma^2{}_d$, the variance of $a_1\,d_1+a_2\,d_2+\cdots+a_N\,d_N$, where the a's are constants, is $(a_1{}^2+a_2{}^2+\cdots+a_N{}^2)\,\sigma^2{}_d$, it is evident that

$$\sigma^2_{d1} - \overline{D} = \frac{1}{N^2}\left[(N-1)^2 + (N-1)\right]\sigma^2_d$$
$$= \frac{N-1}{N^2}\left[(N-1)+1\right]\sigma^2_d$$
$$= \frac{(N-1)}{N}\sigma^2_d$$

In the comparison of the quadrats and field plots a different formula was used than when the rod rows were compared with the quadrats and field plots. The reason is that since the quadrats are parts of the field plots, there is a correlation between the yields of the two methods which must be considered. The formula used to determine how much difference is necessary for significance considering the quadrat and field plot yields of a variety is,

$$d = \overline{D} \pm t\sqrt{\frac{s^{2\prime}}{r} \cdot \frac{N-1}{N}},$$

$$\text{where } s^{2\prime} = \frac{\left[\begin{array}{l}\text{error sums of squares for plots} + \text{error sums of} \\ \text{squares for quadrats} - 2 \text{ error cross products} \\ \text{of plots and quadrats}\end{array}\right]}{(N-1)\ (r-1)}$$

and the other symbols have the same meaning as previously indicated.

The data for this part of the study are summarized in Table 2. The yield of the 1937 spring wheat test is very small due to severe damage from stem rust and hessian fly.

In only 2 of the 19 trials involving a comparison of quadrats and field plots was the interaction of variety×method significant. The largest discrepancy between the two methods occurred in the 1938 barley trial where 5 of 14 varieties reacted differently. The year 1937 was a very unfavorable one for barley production at Madison. A wet spring delayed planting until the first week in May. A severe epidemic of stem rust resulted in shriveled grain. The degree of shriveling was more pronounced in some varieties than in others. In order to plant the same number of viable kernels per plot for each variety, the sowing rate for the variety was calculated based on percentage germination and weight per kernel. The resulting stands were thin in 1938, especially for certain varieties. The barley was also badly lodged which, with an uneven stand, resulted in considerable difficulty in harvesting the quadrats. This may explain in part the discrepancy in the varietal reaction for the two methods. In the 1938 winter wheat test 2 of 11 varieties tested reacted differently to the two methods. In all other trials the relative yields of the varieties for the two methods were essentially the same. This does not mean that in a particular trial the quadrat yield can be substituted for that of the entire plot for some of the varieties and not for others. An examination of the means for the two methods shows that in certain tests the yield when expressed in bushels per acre was higher for the quadrats while in other tests the reverse is true. For all tests the mean yields of the quadrats, field plots, and the rod rows were 35.0, 33.7, and 38.3 bushels per

TABLE 2.—*Comparison of the variety × method of testing interaction for quadrat, field plot, and rod-row plot methods of determining yields of small grains at Madison, Wis.*

| Year | Number of varieties | Mean yield of grain per acre and coefficient of variability | | | | | | Comparison of variety × method of testing interaction | | | | | | F value | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Quadrats | | Field plots | | Rod rows | | Quadrats and field plots | | Quadrats and rod rows | | Field plots and rod rows | | | |
| | | Mean, bu. | C.V.,* % | Mean, bu. | C.V., % | Mean, bu. | C.V., % | F value | N† | F value | N† | F value | N† | .05 | .01 |
| | | | | | | Oats | | | | | | | | | |
| 1937 | 10 | 50.7 | 8.2 | 45.6 | 9.8 | 52.5 | 14.9 | 0.7 | 0 | 1.6 | 0 | 2.3 | 0 | 2.1 | 2.8 |
| 1938 | 17 | 25.9 | 17.4 | 30.9 | 18.6 | 33.7 | 18.7 | 0.8 | 0 | 5.6 | 2 | 3.2 | 1 | 1.8 | 2.2 |
| 1939 | 15 | 44.6 | 18.3 | 44.8 | 18.1 | 57.5 | 13.7 | 0.4 | 0 | 3.1 | 2 | 3.8 | 2 | 1.8 | 2.3 |
| 1940 | 16 | 74.9 | 7.8 | 77.6 | 8.6 | 75.6 | 13.3 | 0.7 | 0 | 1.1 | 0 | 0.9 | 0 | 1.8 | 2.2 |
| 1941 | 15 | 73.4 | 10.8 | 69.1 | 12.6 | 59.6 | 14.5 | 1.3 | 0 | 4.7 | 3§ | 7.4 | 6§ | 1.8 | 2.3 |
| 1942 | 15 | — | — | 74.6 | 7.4 | 72.5 | 15.3 | — | — | — | — | 2.5 | 2 | 1.8 | 2.3 |
| Mean‡ | | 53.9 | 12.5 | 53.6 | 13.5 | 55.8 | 15.2 | | | | | | | | |
| | | | | | | Barley | | | | | | | | | |
| 1937 | 14 | 24.5 | 15.4 | 22.7 | 13.6 | 27.7 | 15.0 | 1.4 | 0 | 1.8 | 0 | 2.1 | 1 | 1.8 | 2.4 |
| 1938 | 14 | 30.1 | 10.2 | 26.0 | 11.0 | 42.6 | 14.5 | 8.6 | 5 | 4.0 | 1 | 1.4 | 0 | 1.8 | 2.4 |
| 1939 | 5 | 22.3 | 16.5 | 24.2 | 11.6 | 41.4 | 10.1 | 0.6 | 0 | 7.8 | 1 | 11.2 | 1 | 2.8 | 4.2 |
| 1940 | 5 | 41.6 | 13.8 | 43.7 | 11.0 | 44.7 | 10.8 | 2.0 | 0 | 1.5 | 0 | 2.8 | 0 | 2.8 | 4.2 |
| 1941 | 4 | 46.0 | 5.4 | 43.1 | 8.8 | 39.7 | 13.7 | 0.6 | 0 | 2.3 | 0 | 1.2 | 0 | 3.2 | 5.1 |
| Mean | | 32.9 | 12.3 | 31.9 | 11.2 | 39.2 | 12.8 | | | | | | | | |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Winter Wheat | | | | | | | | | | | | | | | |
| 1938 | 11 | 37.8 | 7.9 | 29.6 | 8.0 | 35.8 | 13.9 | 2.8 | 2 | 0.7 | 0 | 2.5 | 1 | 2.0 | 2.6 |
| 1939 | 5 | 28.2 | 9.7 | 27.7 | 7.6 | 31.8 | 16.5 | 1.0 | 0 | 1.1 | 0 | 1.6 | 0 | 2.8 | 4.2 |
| 1940 | 10 | 37.2 | 16.8 | 35.4 | 13.3 | 39.8 | 13.9 | 0.1 | 0 | 0.9 | 0 | 0.9 | 0 | 2.1 | 2.8 |
| 1941 | 12 | 28.3 | 12.1 | 25.4 | 15.3 | 26.5 | 22.3 | 0.8 | 0 | 1.1 | 0 | 1.3 | 0 | 2.0 | 2.6 |
| 1942 | 11 | — | — | 38.8 | 8.1 | 41.3 | 12.0 | — | — | — | — | 1.7 | 0 | 2.0 | 2.6 |
| Mean‡ | | 32.9 | 11.6 | 29.5 | 11.1 | 33.5 | 16.7 | | | | | | | | |
| Spring Wheat | | | | | | | | | | | | | | | |
| 1937 | 12 | 4.9 | 22.9 | 3.9 | 32.9 | 7.0 | 23.3 | 0.2 | 0 | 2.5 | 1 | 3.3 | 2 | 1.9 | 2.5 |
| 1938 | 9 | 22.0 | 9.6 | 21.3 | 8.7 | 22.0 | 14.7 | 0.9 | 0 | 7.4 | 2 | 7.9 | 2 | 2.2 | 3.1 |
| 1939 | 9 | 13.9 | 14.3 | 13.7 | 16.1 | 22.7 | 7.4 | 1.6 | 0 | 2.1 | 0 | 2.0 | 0 | 2.1 | 2.9 |
| 1940 | 9 | 32.0 | 11.5 | 32.9 | 8.1 | 43.2 | 10.4 | 0.1 | 0 | 2.3 | 0 | 2.7 | 0 | 2.1 | 2.9 |
| 1941 | 12 | 26.4 | 9.8 | 24.1 | 9.8 | 23.5 | 15.0 | 0.9 | 0 | 8.1 | 4 | 8.2 | 4 | 1.9 | 2.5 |
| 1942 | 8 | — | — | 29.2 | 8.0 | 30.0 | 11.9 | — | — | — | — | 2.2 | 0 | 2.2 | 3.1 |
| Mean‡ | | 19.8 | 13.6 | 19.2 | 15.1 | 23.7 | 14.2 | | | | | | | | |
| Mean for all crops‡ | | 35.0 | 12.5 | 33.7 | 12.8 | 38.3 | 14.6 | | | | | | | | |

*Coefficient of variability.
†Number of varieties significant at .01.
‡1942 data not included in Means.
§Explanation given in text.

acre, respectively. The mean coefficients of variability for the three methods were 12.5%, 12.8%, and 14.6%, respectively. Since quadrats were not harvested in 1942, the results from the 1942 rod rows and field plots are not included in the above means. The close agreement between the mean coefficient of variability for the quadrats and field plots indicates that the precisions of the two methods are essentially the same.

The F value for the interaction variety × method of testing was equal to or greater than the 0.5 level of significance for 14 tests out of 22 and for 11 tests out of 19, respectively, for the comparisons of the field plots and quadrats results with those of the rod rows. In most instances the significant F value was the result of one or two varieties which responded differentially for the testing methods compared. The number of individual varietal interactions which exceeded the .01 level of significance for the comparisons of field plots and quadrats with rod rows were, respectively, 16 out of 238 and 13 out of 204. The individual varietal interactions exceeding the .01 level of significance for the 1941 oat trial are not included for reasons explained later. The results indicate a good agreement for a large majority of the varieties tested when grain yields from field plots and quadrats are compared with those from rod rows.

In the 1941 oat trials six and three varieties, respectively, reacted significantly different in the field plots and the quadrats as compared to their reaction in the rod rows. A serious epidemic of crown rust, which was much more severe in the field plots than in the rod rows, occurred in 1941. Nine out of the 15 varieties compared were resistant to crown rust; the other six being susceptible. The differences in yields of the susceptible and resistant groups for the quadrats, field plots, and rod rows were, respectively, 39.4, 42.5, and 17.0 bushels per acre. The sums of squares for the interaction variety × method in the comparisons of both the field plots and quadrats with rod rows were separated into two parts, namely, the interaction of the two groups of varieties with methods and the interaction between varieties and methods within groups. The latter interaction in both comparisons was not significant.

Four of the 12 spring wheats compared in 1941 reacted differently in the rod rows than they did in the quadrats or 1/60-acre plots. No reason can be offered to explain this discrepancy, except that the field plots and rod-row plots were located in different fields. It is to be expected that certain varieties, when grown under slightly different environments of different fields, together with the effect of differences in type of plot, would react somewhat differently in respect to other varieties for the rod row and field plots.

## COMPARISON OF PRECISION OF DIFFERENT NUMBERS OF QUADRATS PER FIELD PLOT

Under certain conditions it may be necessary or desirable to use quadrats to determined the yields of experimental plots. Where lodging is severe the harvesting of the entire plot may be considerably more costly and less accurate than an adequate number of quadrats.

For outlying experiments, where facilities are not available to harvest entire plots, quadrats may be used to advantage. The relative cost of the two methods of harvesting will depend principally upon the equipment available at a given station. At the University Hill Farms, Madison, Wis., the cost of harvesting and threshing the entire field plot is approximately twice that where four quadrats are taken from each plot. Where quadrats do not provide sufficient seed, it would be necessary to harvest one or more replicates of the entire plot. It is possible to increase the precision of the quadrat method in two ways, namely, by increasing the number of quadrats per plot or the number of replicates in the experiment.

Field experiments in which quadrats are harvested to represent the larger plot have two sources of random variation, the sampling and experimental errors. The sampling error is the random variation between quadrats within a plot. The experimental error is made up of two sources of variation, the random variation of plots within a replicate and the sampling error. These two sources of variation are independent of each other. The first of these variances is designated as A, while the second, the variance of the mean of k quadrats about the mean of the plot is B/k. The experimental error mean square in terms of plot means is, therefore, $A+\frac{B}{k}$, which on the basis of an individual quadrat would be $k\left(A+\frac{B}{k}\right)=k\,A+B.$

From a study of the composition of the two portions of the experimental error, using the procedure given by Snedecor (17), it is possible to estimate the relative efficiency of increasing both the number of quadrats per plot and the number of plot replications. The procedure followed was to obtain the estimated variance of a varietal mean on a single plot basis, $V_{\bar{x}}=\frac{kA+B}{kr}$, for different numbers of quadrats (k) and replications (r). The relative precision factor was calculated for several different combinations of quadrats and replications by dividing the $V_{\bar{x}}$ of that combination into the $V_{\bar{x}}$ where k and r were both equal to 4. The results are given in Table 3.

The data for the 1937 oat trial are used to illustrate the calculations discussed above.

| | | |
|---|---|---|
| Experimental error | $(kA+B)=70.68$ | |
| Sampling error | $B=33.45$ | |
| | $kA=37.23$ | $A=9.31$ |

$$V_{\bar{x}} \text{ where } k=4, r=4 \text{ is} = \frac{70.68}{(4)(4)}=4.42$$

$$V_{\bar{x}} \text{ where } k=3,\ r=4 \text{ is} = \frac{3(9.31)+33.45}{(4)\ (3)}=5.12$$

$$\text{Relative precision factor is } \frac{4.42}{5.12}=86$$

TABLE 3.—*The estimated variances of varietal means and the relative precision factors for different numbers of replications and quadrats per plot based on field plots at Madison, Wis.**

| Year | Mean square: Experimental error† $kA+B$ | Mean square: Sampling error $B$ | Estimated variance of a plot $A$ | k=4; r=4 $V_{\bar{x}}$‡ | k=3; r=4 $V_{\bar{x}}$ | k=3; r=4 P.F.§ | k=6; r=4 $V_{\bar{x}}$ | k=6; r=4 P.F. | k=8; r=4 $V_{\bar{x}}$ | k=8; r=4 P.F. | k=6; r=3 $V_{\bar{x}}$ | k=6; r=3 P.F. | k=3; r=5 $V_{\bar{x}}$ | k=3; r=5 P.F. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Oats | | | | | | | |
| 1937 | 70.68 | 33.45 | 9.31 | 4.42 | 5.12 | 86 | 3.72 | 119 | 3.37 | 131 | 4.96 | 89 | 4.09 | 108 |
| 1938 | 101.16 | 41.40 | 14.94 | 6.32 | 7.19 | 88 | 5.46 | 116 | 5.03 | 126 | 7.28 | 87 | 5.75 | 110 |
| 1939 | 267.66 | 36.21 | 57.86 | 16.73 | 17.48 | 96 | 15.97 | 105 | 15.60 | 107 | 21.30 | 79 | 13.99 | 120 |
| 1940 | 136.88 | 70.24 | 16.66 | 8.56 | 10.02 | 85 | 7.09 | 121 | 6.36 | 135 | 9.46 | 90 | 8.01 | 107 |
| 1941 | 251.34 | 102.78 | 37.14 | 15.71 | 17.85 | 88 | 13.57 | 116 | 12.50 | 126 | 18.09 | 87 | 14.28 | 110 |
| Mean | | | | | | 89 | | 116 | | 125 | | 86 | | 111 |
| | | | | | | | Barley | | | | | | | |
| 1937 | 57.17 | 15.01 | 10.54 | 3.57 | 3.89 | 92 | 3.26 | 110 | 3.10 | 115 | 4.35 | 82 | 3.11 | 115 |
| 1938 | 38.31 | 5.34 | 8.22 | 2.39 | 2.50 | 96 | 2.29 | 105 | 2.22 | 108 | 3.04 | 79 | 2.00 | 120 |
| 1939 | 54.71 | 9.31 | 11.35 | 3.42 | 3.61 | 95 | 3.23 | 106 | 3.13 | 109 | 5.10 | 60 | 2.89 | 118 |
| 1940 | 131.49 | 58.94 | 18.14 | 8.22 | 9.45 | 87 | 6.99 | 118 | 6.38 | 129 | 9.32 | 88 | 7.56 | 109 |
| Mean | | | | | | 92 | | 110 | | 116 | | 77 | | 116 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Spring Wheat** | | | | | | | | | | | | | | |
| 1937 | 5.06 | 1.96 | 0.78 | 0.32 | 0.36 | 89 | 0.28 | 114 | 0.26 | 123 | 0.37 | 86 | 0.29 | 110 |
| 1938 | 17.96 | 10.86 | 1.78 | 1.12 | 1.35 | 83 | 0.90 | 124 | 0.78 | 144 | 1.20 | 93 | 1.08 | 104 |
| 1939 | 15.74 | 4.80 | 2.74 | 0.99 | 1.09 | 90 | 0.89 | 111 | 0.84 | 118 | 1.18 | 84 | 0.87 | 114 |
| 1940 | 54.16 | 14.98 | 9.80 | 3.39 | 3.70 | 92 | 3.07 | 110 | 2.92 | 116 | 4.10 | 83 | 2.96 | 115 |
| 1941 | 27.18 | 13.54 | 3.41 | 1.70 | 1.98 | 86 | 1.42 | 120 | 1.28 | 133 | 1.89 | 90 | 1.58 | 108 |
| Mean | | | | | | 88 | | 116 | | 127 | | 87 | | 110 |
| **Winter Wheat** | | | | | | | | | | | | | | |
| 1938 | 35.81 | 25.87 | 2.49 | 2.24 | 2.78 | 81 | 1.70 | 132 | 1.43 | 157 | 2.27 | 99 | 2.22 | 101 |
| 1939 | 30.04 | 15.96 | 3.52 | 1.88 | 2.21 | 85 | 1.55 | 121 | 1.38 | 136 | 2.06 | 91 | 1.77 | 106 |
| 1940 | 157.44 | 29.60 | 31.96 | 9.84 | 10.46 | 94 | 9.22 | 107 | 8.92 | 110 | 12.30 | 80 | 8.37 | 118 |
| 1941 | 46.53 | 13.04 | 8.37 | 2.91 | 3.18 | 92 | 2.64 | 110 | 2.50 | 116 | 3.51 | 83 | 2.54 | 115 |
| Mean | | | | | | 88 | | 118 | | 130 | | 88 | | 110 |
| Mean for all crops..... | | | | | | 89 | | 115 | | 124 | | 85 | | 112 |

*All numerical values in this table, save the precision factors, are in bushels per acre.
†Experimental error expressed on the basis of a single quadrat.
‡k = Quadrats, r = Replicate; $V_{\bar{x}}$ = Estimated variance of a varietal mean.

§P.F. = Precision factor.

The precision of the experiment can be increased by diminishing either or both portions of the experimental error. Before this is done it is desirable to express the two portions on a common basis so that their relative size may be readily ascertained as follows:

$$V_{\bar{x}} = \frac{kA+B}{r\,k} = \frac{A}{r} + \frac{B}{rk},$$

which for the 1937 oat trial is, $\frac{9.31}{4} + \frac{33.45}{16} = 2.33 + 2.09 = 4.42.$

Where A is small with respect to B, as is the case of the 1938 winter wheat, the precision of the experiment can be increased considerably by increasing the number of quadrats per plot. On the basis of this trial the estimated precision factor resulting from an increase of the number of quadrats per plot from four to six is 32%. This indicates that four replicates with six quadrats per plot would be slightly better than five replicates with four quadrats per plot. Where A is large in relation to B, as in the 1939 oat trial, the precision can be increased most rapidly by increasing the number of replications. In this case an increase in the number of quadrats per plot from four to six and to eight would give, respectively, increases in precision of 5% and 7%, whereas a reduction in number of quadrats to three and an increase in replicates to five would give a 20% increase in precision.

An examination of the relative precision factors for the several combinations of k and r given in Table 3 show considerable fluctuation from year to year within a crop. This indicates that it would be undesirable to make a recommendation based on the results of a single test. A comparison of the average precision factors for the different cereals shows a very close agreement, especially for the oats, spring wheat, and winter wheat. For the barley the data indicate that increasing the number of replicates would be relatively more effective than increasing the number of quadrats per plot as compared to the other crops. The estimated relative precision factor for different numbers of quadrats per plot and replications per trial are shown graphically in Fig. 1. These values are based upon the mean relative precision factors for all crops given in Table 3. Since the estimated variance of a varietal mean is given by $\frac{kA+B}{kr}$, the relation between A and B was obtained from:

$$\frac{4A+B}{16} = 100$$

$$\frac{3A+B}{12} + \frac{6A+B}{24} + \frac{8A+B}{32} + \frac{6A+B}{18} + \frac{3A+B}{15} = 100\left(\frac{100}{89} + \frac{100}{115} + \frac{100}{124} + \frac{100}{85} + \frac{100}{112}\right)$$

Accordingly, A = 243.96 and B = 624.16. The relative precision factor, expressed in percentage of r = 4, k = 4 as 100, was obtained for

different combinations of r and k by solving the equation $X = \dfrac{100}{\dfrac{kA+B}{kr}}$

which for k=5 and r=4 is $\dfrac{100}{\dfrac{5(243.96)+624.16}{20}} = 108.$

The relative precision factors based on all 19 trials show that an increase in the number of replications would be more effective than an increase in the number of quadrats per plot. If a total of 24 quadrats are to be harvested, the estimated relative precision for the combinations of r=2 and k=12, r=3 and k=8, r=4 and k=6, and r=6 and k=4 are, respectively, 68, 93, 115, and 150. In any comparison of the above values the increased cost resulting from an increase in the number of replications must be considered.

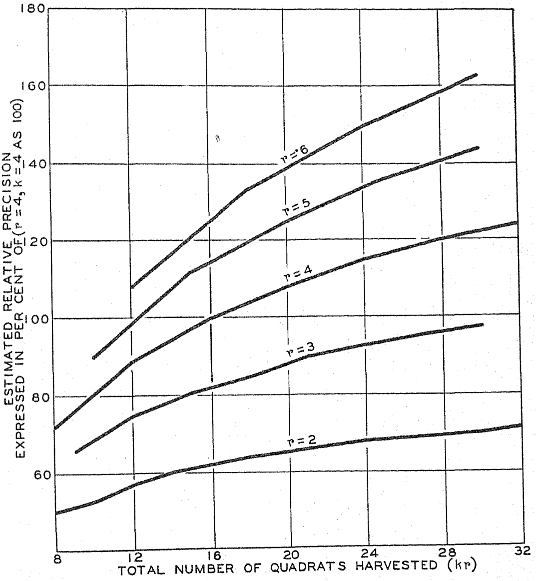


FIG. 1.—Estimated relative precision for different number of replicates and quadrats per plot expressed in percentage of the value for four replicates and four quadrats per plot as 100, based on data from field plots at Madison, Wis.

The data in Table 2 show that the coefficients of variability for the quadrats and the field plots were similar. This indicates that the use of four quadrats gave essentially as precise information as harvesting the entire plot. On the basis of the results in Table 3 the precision of a test can be increased 25% by using five replicates with four quadrats per plot or four replicates with eight quadrats per plot. The procedure to be recommended to increase precision depends largely upon cost factors and the availability of land. If land is not the limiting factor and the cost of an additional replication is less than that of doubling the number of quadrats per plot, it would be advisable to plant an additional replicate. However, if land is limited or if increasing the number of quadrats is more economical than increasing the number of replicates, eight quadrats with four replicates would be recommended. The ultimate answer to the question would depend largely upon the characteristics peculiar to the experiment station concerned.

## SUMMARY

1. The precision of the lattice design, with and without recovery of inter-block information, as compared to the randomized complete block design was determined for 22 small grain trials. The average of all tests gave an increase of 9% in precision with recovery of inter-block information and a loss of 8% when inter-block information was ignored.

2. Four quadrats harvested from 1/60- or 1/80-acre field plots provided, for the most part, reliable estimates of the yield of the entire plot. The precision of the quadrats as measured by the coefficient of variability is essentially the same as that of the field plots.

3. A good agreement was found for most of the varieties tested when grain yields from rod-row plots were compared with those from field plots and quadrats.

4. Calculations based on the 19 field plot trials showed that increasing the number of replications would be more effective than increasing the number of quadrats per plot as a means of increasing precision.

5. The average precision factors calculated for different numbers of quadrats and replicates were essentially the same for the different cereals, especially for oats, spring wheat, and winter wheat.

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# BORDER EFFECT IN SOYBEAN NURSERY PLOTS[1]

A. H. PROBST[2]

ONE of the most important factors in connection with breeding soybeans is the accurate evaluation of new strains in the yield-testing program. This is especially true when testing strains in which there is not much spread in the yields. Published data on plot technics with this crop are very limited.

In an effort to evaluate some of the present plot technics used in soybean testing, a study of border effect was undertaken at Lafayette, Ind., by the U. S. Regional Soybean Industrial Products Laboratory[3] and Purdue University Agricultural Experiment Station[4] cooperating, with four varieties of soybeans. The work was conducted over the 4-year period from 1938 to 1941, inclusive.

The data of Arny and Hayes (1)[5] show increases in yield resulting from border effect from only the sides of plots which varied from 7.9 to 15.3% with an average of 12.5% in oats, from 14.1 to 23.7% with an average of 18.4% in wheat, and from 21.1 to 45.8% with an average of 26.3% in barley. They observed a rearrangement in yield rank due to border effect and decided to remove the plants from an area at least 1 foot wide within the margins of variety test plots to obliterate border effect.

Love and Craig (3), in discussing cereal breeding methods, state that, "It is obvious that if the end of each row is cut off, more nearly uniform conditions may be obtained and the effect of increased nutrition which occurs at the ends will not enter into the calculations and modify the results."

McClelland (4) shows increases in yield of 8.3%, 8.5% and 7.4%, respectively, for winter oats, winter wheat, and spring oats due to border effect. He concluded that removing or including the border rows made little difference in the comparison of yields.

From the data obtained by McRostie and Hamilton (5) with grasses and legumes they concluded that, "The inclusion of the border foot in plats surrounded by cultivated paths is associated with inaccuracy of result". Their data on yields of individual plants of western rye grass show increases ranging from 5.87 to 54.11% attributed to border effect.

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[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, and Bureau of Agricultural and Industrial Chemistry, U. S. Regional Soybean Industrial Products Laboratory, U. S. Dept. of Agriculture, and Purdue University Agricultural Experiment Station, Lafayette, Indiana, cooperating. Received for publication September 4, 1942.

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[3]A cooperative organization participated in by the Bureaus of Agricultural and Industrial Chemistry and Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, of the U. S. Dept. of Agriculture, and the Agricultural Experiment Stations of the North Central states of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin.

[4]Journal paper No. 22, Purdue University Agricultural Experiment Station.

[5]Figures in parenthesis refer to "Literature Cited", p. 666.

Hollowell and Heusinkveld (2), working with alfalfa and red clover, state that, "To discard the two rows next to the alley at harvest would minimize border effect as a source of error in securing yields from experimental plats".

## MATERIALS AND METHODS

In order to determine (a) border effect in soybean nursery rows and (b) the resulting grain yields which might be obtained from trimming rows at maturity compared to trimming soon after emergence, the Mukden, Mandell, Dunfield, and Illini varieties were used. Mukden is the earliest of these varieties in maturity and Illini the latest at Lafayette, Ind. The study was conducted on a Brookston-Crosby soil complex.

A split-plot Latin square design was used with four replications of each variety. Excessive amounts of seed of each variety were planted in single row plots 20 feet long with 30 inches between rows. Each row was trimmed to exactly 18 feet in length after the plants emerged and the plants were thinned in the row to approximately 1 inch apart. Alleys 3 feet wide remained after trimming.

The border effect within the rows was determined by removing four successive sections of plants from each end of each 18 foot row. The sections were 6 inches in length. The seed from the outer 6-inch sections from each end of a row were combined and designated as section one, the successive sections in order were treated similarly and, respectively, designated as section two, three, and four. Thus each section contained the quantity of seed from a linear foot of row.

The method used to obtain the grain yields from rows trimmed soon after emergence compared to those obtained when the rows were trimmed at harvest consisted of adding the weight of the seed from the two outer sections, one and two, to the weight of seed obtained in the 14-foot row length remaining after the four sections were removed. This is designated as trimmed at emergence. In a similar manner the seed weight obtained from sections three and four was added to the weight of the seed obtained in the 14-foot row. This is designated as trimmed at maturity.

## EXPERIMENTAL RESULTS

### DETERMINATION OF BORDER EFFECT

The data in Tables 1 and 2 show that there is considerable border effect on the ends of the rows, particularly in section one which yields highly significantly greater than any other section. No significant difference in weight of seed was obtained within varieties between sections three and four in any year, or in the summary for the 4-year period. The yields have averaged somewhat higher in section four than in section three. There is not always a significant difference between sections two and three or between two and four. In 1939 and 1940 section two was not significantly higher in yield than either section three or section four with any variety. Section two of the Mukden variety did not yield significantly more than sections three or four in any single year or in the mean of the four years. In two years section three or four outyielded section two. It appears that Mukden does not respond as much to border effect as the other varieties.

TABLE 1.—*The mean weight of seed obtained from different 1-foot sections of soybean nursery rows with four varieties of soybeans during 4 years, 1938–41, at Lafayette, Indiana.*

| Varieties | Four-year mean weight in grams* | | | |
|---|---|---|---|---|
| | Section one | Section two | Section three | Section four |
| Illini | 165.0 | 68.1 | 45.5 | 55.8 |
| Mandell | 151.3 | 76.4 | 56.2 | 50.5 |
| Dunfield | 158.1 | 63.3 | 43.6 | 50.6 |
| Mukden | 137.4 | 58.0 | 51.8 | 52.6 |
| Section means† | 153.0 | 66.4 | 49.3 | 52.4 |

Analysis of Variance

| Source of variation | Degrees of freedom | Mean squares |
|---|---|---|
| Years | 3 | 6,365.00** |
| Varieties | 3 | 1,110.67 |
| Varieties × years | 9 | 699.22** |
| Error (a) | 24 | 88.00 |
| Sections | 3 | 153,986.33** |
| Sections × years | 9 | 1,472.56** |
| Sections × varieties | 9 | 906.00** |
| Sections × varieties × years | 27 | 380.33 |
| Error (b) | 144 | 349.97 |

*A difference of 21.2 grams is significant between varieties within sections; a difference of 13.1 grams is significant between sections within varieties.
†A difference of 6.5 grams is significant between means of sections.
**Highly significant differences.

TABLE 2.—*The mean weight of seed in grams obtained from four different sections of soybean nursery rows by individual years for four varieties of soybeans.*

| Year | Section one | Section two | Section three | Section four | Difference necessary for | |
|---|---|---|---|---|---|---|
| | | | | | Significance | High significance |
| 1938 | 183.8 | 80.7 | 57.8 | 52.9 | 12.1 | 16.3 |
| 1939 | 150.4 | 62.2 | 46.2 | 61.8 | 19.0 | 25.6 |
| 1940 | 130.6 | 58.6 | 45.1 | 45.3 | 10.7 | 14.4 |
| 1941 | 147.2 | 64.3 | 48.0 | 49.5 | 9.5 | 12.7 |
| Mean | 153.0 | 66.4 | 49.3 | 52.4 | 6.5 | 8.6 |

From these data it is evident that border effect may be eliminated by removing a foot section from each end of the row at maturity. It is likewise evident that all varieties do not respond the same in production on the ends of the rows.

## YIELDS OBTAINED BY END TRIMMING AT EMERGENCE AND AT MATURITY

The results for the mean of the 4-year period are shown in Table

3, and the results of the combined varieties for individual years appear in Table 4.

TABLE 3.—*Four-year summary, 1938–41, of the effect on yield from trimming soybean nursery plot rows soon after emergence and at maturity.*

| Varieties | Trimmed after emergence | | Trimmed at maturity | | Difference between treatments | |
|---|---|---|---|---|---|---|
| | Bu. per acre | Rank | Bu. per acre | Rank | Bu. per acre | Percentage |
| Illini.......... | 37.5 | 1 | 32.0 | 2 | 5.5 | 17.2 |
| Mandell....... | 37.2 | 2 | 32.6 | 1 | 4.6 | 14.1 |
| Dunfield...... | 35.4 | 3 | 30.0 | 4 | 5.4 | 18.0 |
| Mukden...... | 34.8 | 4 | 30.6 | 3 | 4.2 | 13.7 |
| Means........ | 36.2 | | 31.3 | | 4.9 | 15.7 |

TABLE 4.—*Mean yields in bushels per acre by individual years of the effect on yield from trimming soybean nursery rows soon after emergence and at maturity with four varieties of soybeans.*

| Years | Trimmed after emergence | Trimmed at maturity | Difference between treatments | |
|---|---|---|---|---|
| | | | Bu. per acre | % |
| 1938............. | 42.0 | 35.0 | 7.0 | 20.0 |
| 1939............. | 36.4 | 32.2 | 4.2 | 13.0 |
| 1940............. | 31.1 | 27.1 | 4.0 | 14.8 |
| 1941............. | 35.4 | 30.8 | 4.6 | 14.9 |
| Treatment means | 36.2 | 31.3 | 4.9 | 15.7 |

All varieties yielded considerably higher when trimmed at emergence than when trimmed at maturity in each of the individual years, as well as for the average of the 4 years. There was considerable fluctuation in the percentage increase in yield due to border effect between varieties within individual years as well as within varieties in different years, as shown in Table 5. Mandell and Mukden, in all cases but one, gave smaller increases in each year than Dunfield and Illini, which might indicate a differential foraging ability between the different varieties. There might also be some association with

TABLE 5.—*Percentage increase due to border effect for each variety, 1938–41.*

| Varieties | 1938 | 1939 | 1940 | 1941 | Mean |
|---|---|---|---|---|---|
| Illini............................ | 21.5 | 17.1 | 16.7 | 13.9 | 17.3 |
| Mandell......................... | 15.3 | 10.6 | 13.9 | 15.4 | 13.8 |
| Dunfield........................ | 23.2 | 14.4 | 17.5 | 17.6 | 18.2 |
| Mukden......................... | 21.2 | 10.6 | 10.2 | 12.8 | 13.7 |
| Mean............................ | 20.0 | 13.2 | 14.6 | 14.9 | 15.7 |

time of maturity in that the latter varieties are a few days later. Mukden branches the least, but there is no especially noticeable difference in the other three varieties. Even though there are appreciable differences in percentage increase between varieties, as shown in Table 5, these differences are quite small on an acre yield basis, as shown in Table 3. There is a rearrangement in yield rank under the two systems.

From these data it is observed that yields are lower when the rows are trimmed at maturity than when an accurate row length is established soon after emergence. The former method in all probability more nearly approximates the actual yields of varieties under field conditions than the latter method. It is also seen that on the basis of the percentage increases in yield due to border effect varieties do not react the same. The small differences in the actual yields do not warrant concluding, from the varieties worked with and the methods employed, that one system is better than the other. It is well to keep in mind, however, that trimming at maturity assures one of a constant row length, whereas in trimming at emergence the rows might vary due to the hazards encountered during the growing season. Likewise, data without border effect removed might be considered questionable if presented to farmers in that as a group farmers are more concerned with actual field results than with relative yields.

## CONCLUSIONS

Border effect is very evident among the plants in the outer foot of soybean nursery rows adjacent to 3-foot alleys. This effect may be eliminated by removing the outer foot of row length of plants at maturity.

Yields were on the average 16% higher in single-row soybean nursery plots 16 feet long and 30 inches between rows when border effect was not removed.

Varieties responded differently with respect to border effect but not enough to give a marked change in the relative yields.

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# MATURITY MEASUREMENTS IN CORN AND AN INDICATION THAT GRAIN DEVELOPMENT CONTINUES AFTER PREMATURE CUTTING[1]

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ATTENTION given to maturity measurements in corn and means for comparing relative maturities among strains has increased considerably since it has become necessary in modern testing programs to evaluate large numbers of hybrid combinations. Relative maturities of corn hybrids must be accurately determined in order to measure their relative yielding abilities (19).[3]

Percentage of dry matter or moisture in the grain has received most attention as a measurement of maturity. Several workers have reported moisture values at which they considered the grain development to be completed, as follows:

| Year reported | Investigator | Crop | Moisture at maturity, % |
|---|---|---|---|
| 1920 | Harlan (5) | Barley | 42.0 |
| 1923 | Olson (12) | Wheat | 40.0 |
| 1930 | Burnett and Bakke (3) | Wheat, oats, and barley | Below 40.0 |
| 1934 | Robinson (14) | Corn | 40.0 (air-dry) |
| 1938 | Ohio Agr. Exp. Sta. (11) | Wheat and oats | 40.0 |
| 1939 | Lambert (10) | Corn | 37.5 |
| 1940 | Rather and Marston (13) | Corn | 40.0 |

Yield losses resulting from premature harvesting have been pointed out by Shelton and Cottrell (17) and by Schweitzer (16). Kiesselbach and Lyness (9) reported yield reductions of 7.4% and 10.4%, respectively, when Kherson oats were harvested 4 and 6 days prior to "maturity". Hopper (7) found 68.7%, 98.9%, and 100% of the maximum dry weight in the grain of corn in the dough, glazed, and ripe stages, respectively. Lambert (10) calculated that corn at 75% moisture had produced 15% of its maximum grain yield, at 55% moisture 74%, and at 45% moisture 91% of the maximum yield. Corn harvested at 50% moisture in the grain yielded 10 to 20% less than at 40% or below according to Rather and Marston (13).

Authors do not agree on the translocation of materials into the grain after plants have been cut. Kedzie (8), Briggs (2), Teller (20), Davenport and Frasier (4), and Harlan and Pope (6) found increases in kernel weights of cereal crops when harvested prematurely and dried on the culms.

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[3]Figures in parenthesis refer to "Literature Cited", p. 680.

Arny and Sun (1) and Wilson and Raleigh (22) reported no appreciable increases in wheat or oats regardless of the stage of development when cut or the method of drying. An Ohio Agricultural Experiment Station report (11) stated that, "The yield of corn will be reduced if it is cut before the well glazed stage . . . . . . . . . . . . . . . . Corn does not ripen in the shock, it merely dries out."

The term "maturity" has not been clearly defined nor consistently used in the literature. It has, however, been expressed more definitely in recent years, usually in moisture content of the grain. Throughout this paper "maturity" is defined as the point at which maximum grain development is first attained. "Relative maturity" expresses the comparative periods required for strains to reach maximum dry weight of grain.

This paper compares several possible criteria of relative and actual maturities in corn. In addition, data are presented which indicate that grain development continues for a time after corn is prematurely cut and shocked, a common farm practice in Ohio as shown by surveys conducted in 1940 and 1941, and reported in this paper.

## MATERIALS AND METHODS

### MEASUREMENTS OF MATURITY

Ten strains of corn, nine commercial yellow dent hybrids and one open-pollinated variety, with a wide range in lengths of growing season, were planted May 21, 1939, at Kenton, Ohio, in four randomized blocks with plots $2 \times 10$ hills in size. The same strains were planted in $2 \times 20$ hill plots at Columbus, Ohio, on the Agronomy Experiment Farm in 1940 and 1941. Four blocks were planted early in May (May 7, 1940, and May 2, 1941) and four additional blocks planted somewhat later (June 3, 1940, and May 26, 1941). Six kernels were planted and plants were later thinned to uniform stands of three per hill.

Numbers of plants having exposed silks were recorded on alternate days during the silking periods, and mid-silking dates were determined from these data.

All ears from two hills, one selected at random in each row of the plot, were harvested at 4-day intervals during the latter part of the development period of the grain. Composite samples of grain were obtained by shelling four to six rows of kernels from each ear, the number being constant for the ears in a sample. Three rows had previously been removed and discarded, two by means of a screw driver and the third by hand shelling. This was especially necessary in the early harvests to obtain unbroken kernels for the moisture and kernel weight determinations. Shelled samples were placed immediately in moisture-proof envelopes and taken to the laboratory.

Samples were weighed, placed in cloth bags, dried at 65° to 75° C 4 days, and at 85° to 95° C another 4 days. Approximately 1% of moisture remained at the end of this drying treatment. The dried samples were weighed and grams per 100 kernels were determined by averaging the weights of triplicate 100 kernels samples which had been weighed on a torsion balance accurate to 0.01 gram. Plants and ear husks were described and the ears harvested were classified into the following groups in 1940 and 1941:

1. *Early milk.*—Kernels pale yellow in color and not yet maximum size.
2. *Late milk.*—Kernels much deeper yellow in color and having attained maxi-

mum size. Kernels rounded to 20% dented. Average dry matter content of the grain, 40%.

3. *Soft dough.*—20 to 90% of the kernels denting but still easily punctured with the thumbnail. Average dry matter, 50%.

4. *Hard dough.*—Kernels more than 90% dented and difficult to puncture with the thumbnail. Ears remained in this class as long as any milk was present in the bases of kernels opposite the germ faces. Average dry matter, 60%.

5. *Ripe.*—Kernels fully dented and no milk in the bases. Dry matter, 70% or above.

Ear appearance factors from 1 to 5 were calculated for each plot on the basis of the number of ears classified into the five groups described above.

### KERNEL DEVELOPMENT IN SHOCKED CORN

The cutting and shocking study was not planned until near harvest time in 1941 and it was therefore necessary to utilize material which had been planted for other purposes. Ten-hill sections of rows in Iowa 939 and Ohio C 84, and one single-cross hybrid, (Ohio 26×Ohio 51) were cut and shocked at 4-day intervals and tied into two bundles each consisting of five alternate hills. Immediately after cutting, the ears in one of the bundles were sampled in the manner described in an earlier paragraph with the following alterations: (a) They were not removed from the stalks, (b) only a narrow strip of husks was pulled back and later replaced, and (c) only two rows of kernels were shelled from each ear for the composite sample.

Both five-hill bundles were then placed in the center of a small shock of corn. Eight days later the shock was torn apart and all ears in both bundles were sampled. This procedure provided duplicate bundles one of which was sampled only after drying in the shock, and the other sampled both before and after drying. Percentages of dry matter in the grain and weights per 100 kernels were determined as previously outlined.

### TIME OF CUTTING CORN IN OHIO

Surveys covering several sections of Ohio were made in 1940 and 1941 to determine the stages of development at which corn was cut and shocked on farms. Composite samples were obtained from the ears of 20 to 25 representative plants in fields which were being cut. Percentages of dry matter were determined by weighing before and after drying for 8 days at 85° to 95° C.

## DATA AND DISCUSSION

### DAYS TO SILKING

Table 1 gives the number of days from seedling emergence to mid-silking date and from mid-silking to maturity (65% dry matter in the grain).

Strains are listed in Table 1 in order of maturity, the earliest first, on the basis of the dry matter in the grain at harvest (average of the 3 years). It is apparent from the data that silking date is highly indicative of relative maturity. The correlation coefficients between days from seedling emergence to silking and the percentage of dry matter in the grain at harvest time varied from −0.528 to −0.873 for the 1941 harvests, with "r" at the 1% level equal to ±0.418. How-

TABLE 1.—*Days from seedling emergence to mid-silking date and from mid-silking to 65% dry matter in the grain, Columbus, Ohio, 1941.**

| Strains in order of maturity† | Planted May 2 | | Planted May 26 | | Average silking to 65% dry matter, days |
|---|---|---|---|---|---|
| | Emergence to silking, days | Silking to 65% dry matter, days | Emergence to silking, days | Silking to 65% dry matter, days | |
| Ohio M15..... | 62.0 | 48.0 | 59.5 | 47.5 | 48.0 |
| Ohio K23..... | 61.0 | 49.0 | 59.0 | 51.0 | 50.0 |
| Ohio K35..... | 62.0 | 51.0 | 59.5 | 53.5 | 52.0 |
| Woodburn.... | 62.0 | 53.0 | 59.0 | 52.0 | 52.5 |
| Iowa 939...... | 63.0 | 52.0 | 61.0 | 53.0 | 52.5 |
| Ohio W17..... | 65.0 | 51.0 | 62.0 | 50.0 | 50.5 |
| U. S. 65....... | 66.0 | 50.0 | 62.0 | 52.0 | 51.0 |
| Indiana 614... | 66.5 | 51.5 | 63.0 | 55.0 | 53.0 |
| Ohio C84..... | 68.0 | 53.0 | 64.0 | 54.0 | 53.5 |
| U. S. 13....... | 68.0 | 54.0 | 63.0 | 57.0 | 55.5 |
| Significant differences: | | | | | |
| 5% level.... | 0.4 | | 0.6 | | |
| 1% level.... | 0.5 | | 0.8 | | |

*Each figure for number of days is the average of 4 plots.
†Relative maturity based on 3 year average percentages of dry matter in the grain at harvest.

ever, small differences in maturity cannot be predicted from differences in silking date. Ohio M15 silked at the same time as Ohio K 35 and Woodburn and 1 day later than Ohio K 23, but was distinctly earlier than these on the basis of dry matter in the grain (Table 2).

Snelling and Hoerner (18) reported a significant correlation between silking date and percentage of dry matter in the grain on September 14, but an insignificant correlation on October 12. In the present investigation, similar correlation coefficients were calculated for all harvests in two plantings. They decreased steadily from the early to the late harvests in one planting, but no definite trend was found in the second.

## PERCENTAGE OF DRY MATTER IN THE GRAIN

Moisture in the grain has been widely used by research workers during recent years for measuring both relative and actual maturities in corn. In this investigation the percentage of dry matter was calculated rather than the moisture because a curve rising toward maturity seemed preferable to one decreasing and it could also be more readily graphed with the corresponding kernel weights.

Table 2 presents the dry matter percentages of the grain for the two dates of planting in 1941. Differences required for significance are given and their magnitudes indicate that the sampling technic was adequate for plots of this size.

Typical dry matter curves for the three years are given in Figs. 1 to 3. The effect of weather is strikingly illustrated in Fig. 1 on which

TABLE 2.—*Percentage dry matter in the grain of corn, Columbus, Ohio, 1941.*

| Strain | Planted May 2 | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Aug. 4 | Aug. 8 | Aug. 12 | Aug. 16 | Aug. 20 | Aug. 25 | Aug. 29 | Sept. 2 | Sept. 6 | Sept. 10 | Sept. 15 | Sept. 19 | Sept. 23 | Sept. 27 |
| Ohio M15 | 32.3 | 37.5 | 47.1 | 51.7 | 56.0 | 61.4 | 64.0 | 67.8 | 72.1 | 73.8 | 79.0 | 79.7 | 82.8 | — |
| Ohio K23 | 26.8 | 38.0 | 45.6 | 48.0 | 54.0 | 61.0 | 64.5 | 67.4 | 68.7 | 72.6 | 78.7 | 79.2 | 80.3 | — |
| Ohio K35 | 26.7 | 33.6 | 39.9 | 45.4 | 49.0 | 56.0 | 63.0 | 65.2 | 67.8 | 72.3 | 74.6 | 77.9 | 81.4 | — |
| Iowa 939 | 25.4 | 33.6 | 39.0 | 44.4 | 48.5 | 55.3 | 59.2 | 65.8 | 67.8 | 68.4 | 73.2 | 76.5 | 79.1 | — |
| Ohio W17 | 20.8 | 27.7 | 37.7 | 41.0 | 47.4 | 52.9 | 57.8 | 63.6 | 65.5 | 67.8 | 73.6 | 77.0 | 80.8 | — |
| Woodburn | 28.2 | 34.4 | 44.0 | 46.2 | 51.9 | 57.0 | 57.6 | 65.2 | 63.9 | 70.6 | 73.3 | 74.0 | 81.0 | — |
| U. S. 65 | — | — | 38.2 | 41.9 | 48.4 | 53.3 | 58.6 | 62.4 | 66.5 | 70.3 | 74.6 | 76.6 | 80.2 | 79.2 |
| Ind. 614 | — | — | 35.2 | 39.0 | 43.2 | 49.1 | 54.2 | 60.4 | 64.2 | 67.8 | 70.1 | 73.5 | 75.8 | 78.0 |
| Ohio 84 | — | — | — | 35.6 | 42.7 | 47.6 | 50.4 | 58.2 | 61.4 | 64.9 | 69.2 | 72.4 | 76.6 | 77.0 |
| U. S. 13 | — | — | — | 36.4 | 42.0 | 47.6 | 51.8 | 55.9 | 60.0 | 65.2 | 68.6 | 71.8 | 74.8 | 75.0 |

Significant difference, 5% level, 1.5% dry matter
Significant difference, 1% level, 2.0% dry matter

| Strain | Planted May 26 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Aug. 25 | Aug. 29 | Sept. 2 | Sept. 6 | Sept. 10 | Sept. 15 | Sept. 19 | Sept. 23 | Sept. 27 | Oct. 1 | Oct. 6 | Oct. 10 |
| Ohio M15 | 33.8 | 39.6 | 46.1 | 51.9 | 58.9 | 64.3 | 67.4 | 70.5 | 71.9 | 75.4 | 74.7 | 76.2 |
| Ohio K23 | 27.9 | 37.5 | 43.6 | 50.9 | 57.0 | 60.6 | 67.1 | 67.4 | 71.8 | 73.4 | 74.9 | 75.3 |
| Ohio K35 | 26.8 | 34.2 | 40.8 | 45.7 | 50.7 | 57.4 | 61.2 | 67.6 | 70.2 | 73.8 | 72.3 | 75.7 |
| Iowa 939 | 27.6 | 32.6 | 38.4 | 42.7 | 50.8 | 56.9 | 60.9 | 65.4 | 67.0 | 75.1 | 70.8 | 72.6 |
| Ohio W17 | 24.4 | 31.9 | 37.1 | 43.6 | 51.4 | 58.5 | 62.1 | 67.3 | 69.0 | 75.0 | 71.6 | 74.8 |
| Woodburn | 29.7 | 35.1 | 43.0 | 50.5 | 51.5 | 58.2 | 65.0 | 67.3 | 70.4 | 74.1 | 73.2 | 74.9 |
| U. S. 65 | — | — | 41.3 | 47.3 | 51.8 | 56.9 | 61.2 | 64.7 | 68.4 | 72.7 | 71.2 | 74.7 |
| Ind. 614 | — | — | — | 43.5 | 47.5 | 53.0 | 59.3 | 60.9 | 64.6 | 69.0 | 69.2 | 70.5 |
| Ohio 84 | — | — | — | 39.6 | 45.5 | 51.2 | 55.8 | 61.4 | 65.0 | 70.3 | 67.7 | 71.0 |
| U. S. 13 | — | — | — | 42.2 | 45.1 | 51.4 | 57.6 | 58.9 | 63.8 | 66.6 | 66.0 | 70.1 |

Significant difference, 5% level, 1.7% dry matter
Significant difference, 1% level, 2.3% dry matter

pertinent temperature and rainfall data are given. A prolonged drouth preceded the August 28 and September 2 harvests, with the result that 0.47 inch of rainfall on September 4 caused a definite interruption in the rising curve of dry matter in the grain. A similar break occurred after the September 14 harvest which had been preceded by two days of high temperatures and low humidity. Dry matter curves for 1940 rose steadily and the same is true of 1941, except for the period between October 1 and 6 when rain fell daily.

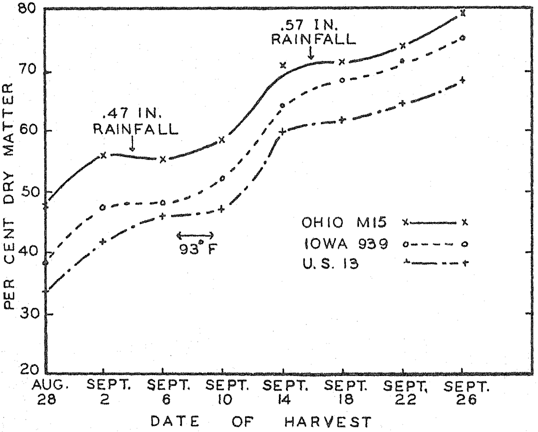


FIG. 1.—Dry matter in the grain of corn planted at Kenton, Ohio, May 21, 1939.

The average increase of dry matter over the entire harvest periods for all strains and all plantings was approximately 1% per day but varied among the three years as follows: 1939, 1.3%; 1940, 0.9%; and 1941, 1.1%. From the time of the first harvest until the maximum kernel weight was reached, the increase was 1.1% per day, and it averaged about 0.6% per day over the remainder of the harvest period.

Differences among the strains in the rates of dry matter increases were not found. However, it would appear that differences existed prior to the time harvesting began inasmuch as Ohio M 15 silked 1 day later than Ohio K 23 in 1941 but was considerably higher in dry matter at the earliest harvest dates. The same is true of U. S. 65 when compared with Iowa 939. Since differences in drying rates were not found during the harvest periods (grain contained 30 to 80% dry matter), it appears that the percentages of dry matter in the grain at harvest may confidently be used to measure relative maturities among strains.

POINT AT WHICH TRANSLOCATION CEASES

An average for the percentage of dry matter in the grain at which the translocation of materials into the kernels ceased was obtained by superimposing dry matter curves (Figs. 1 to 3) upon the corresponding curves for oven-dry weights per 100 kernels (such as Fig. 5). Some of the strains had not reached their maxima at the time of the last harvest and therefore could not be included in the determination of the average figure. The average dry matter in the grain at which translocation ceased (48 values in five plantings) was 66.2% A check on the drying technic showed that slightly over 1% of moisture re-

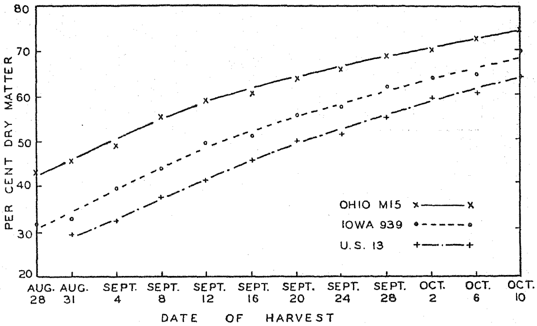


FIG. 2.—Dry matter in the grain of corn planted at Columbus, Ohio, June 3, 1940.

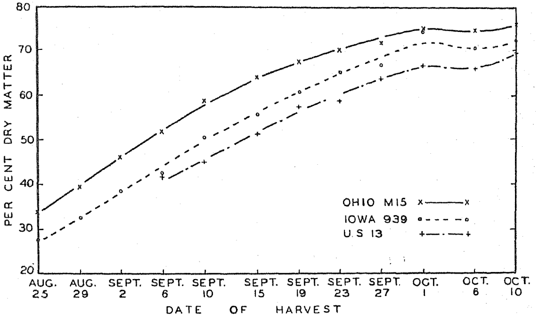


FIG. 3.—Dry matter in the grain of corn planted at Columbus, Ohio, May 26, 1941.

mained after drying so that the corrected value was approximately 65%, or about 5% above the values given by other investigators except Lambert (10). This difference may possibly be attributed to different drying technics which were not always fully described by the authors.

Data obtained indicate that the yield of a plot of corn continues to increase until the dry matter in the grain averages 65%, or the moisture falls to 35%. Translocation into the individual kernels, however, must have ceased at some point below 65% dry matter because this was an average value for the entire sample which included kernels from ears well beyond maturity which would raise the average dry matter above that for the kernels from ears just at the maturity point.

Fig. 4 shows the percentages of maximum kernel weights attained at different levels of dry matter. If future investigation shows that the grain normally increases after corn is cut and shocked, as is suggested elsewhere in this paper, the curve in Fig. 4 should be corrected to compensate for increases found to occur at different moisture levels.

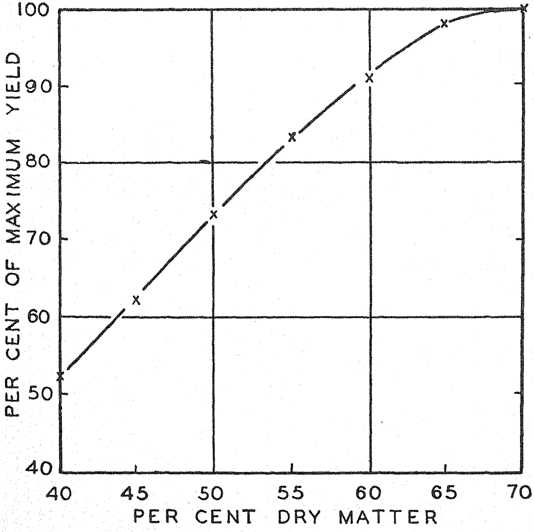


FIG. 4.—Percentage of maximum yield of corn at successive levels of dry matter in the grain. Data are for 1940 and 1941 and are not corrected for increases that may normally occur in the grain of shocked corn.

WEIGHT PER 100 KERNELS

Typical developmental curves for three strains are given in Fig. 5. Temperature and rainfall which altered the course of the percentage of dry matter had little noticeable effect on the kernel weight curves. An increased error in sampling, noted also by Sayre and Morris (15), was evident toward the end of the season in several of the curves, although it does not show in Fig. 5.

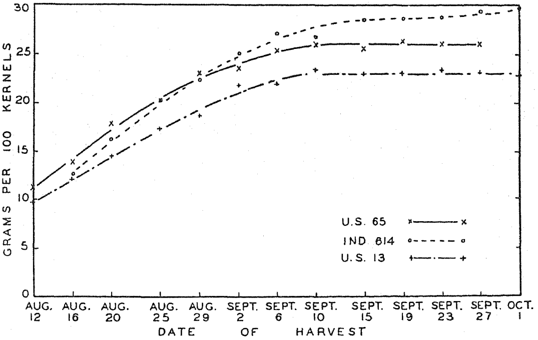


FIG. 5.—Development of the grain in three corn hybrids planted at Columbus, Ohio, May 2, 1941.

EAR APPEARANCE

It is often desirable to estimate the moisture content of the grain of corn during the growing season, and it is especially important to have satisfactory means for describing corn at the time kernel development is completed.

An attempt was made to meet these needs by ranking the ears in 1940 and 1941 on the basis of external appearance into the five groups described under materials and methods. Correlation coefficients between the ear appearance factors and the percentages of dry matter in the grain were +0.953, +0.971, and +0.966 in the June 3, 1940, May 2, 1941, and May 26, 1941 plantings, respectively. These correlations show that it was possible to estimate rather accurately the dry matter in the grain of corn by the method outlined.

The approximate percentages of dry matter corresponding to the ear appearance factors were: 2, late milk, 40%; 3, soft dough, 50%; 4, hard dough, 60%; and 5, ripe, above 70%. An ear appearance factor of about 4.4 corresponded to the point of 65% dry matter in the grain. Maturity, then, was reached when one-third to one-half of the ears in a plot were in the ripe stage and the remainder were in the hard dough stage.

PLANT APPEARANCE AND DRY EAR HUSKS

Plant appearance on each harvest date was noted in 1940 and 1941, and in the latter year the number of dry ear husks per plot was also counted. The number of dead leaves at a given level of moisture in the grain differed greatly between the two years and therefore the appearance of the plant is not considered a satisfactory basis on which to estimate the development of grain.

The time at which the ear husks died or turned straw colored appeared to be more characteristic of the strains and less dependent upon weather conditions than was the appearance of the leaves. Fig. 6 shows the time and rate at which the ear husks died on 6 of the

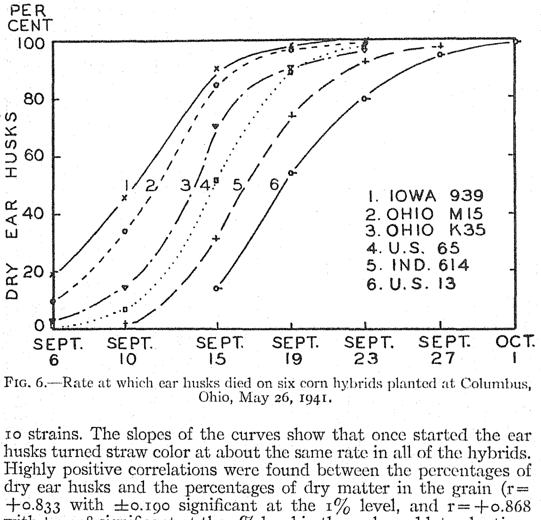


FIG. 6.—Rate at which ear husks died on six corn hybrids planted at Columbus, Ohio, May 26, 1941.

10 strains. The slopes of the curves show that once started the ear husks turned straw color at about the same rate in all of the hybrids. Highly positive correlations were found between the percentages of dry ear husks and the percentages of dry matter in the grain ($r = +0.833$ with $\pm 0.190$ significant at the 1% level, and $r = +0.868$ with $\pm 0.208$ significant at the 1% level in the early and late plantings respectively in 1941). None of the strains studied had reached maximum grain development until at least 90% of the ear husks were dead in 1941.

In spite of the high correlation found between the percentage of dry ear husks and the dry matter in the grain, the number of dry ear husks was not a reliable index of relative maturities among strains of corn. For example, Iowa 939 which ranked no higher than fourth or fifth in dry matter in the grain, showed the highest number of dry ear husks throughout the period over which records were kept.

## KERNEL DEVELOPMENT IN SHOCKED CORN

No record was found in the literature of investigations planned to determine whether translocation of materials into the grain continued after corn was cut and shocked. A survey in 1940 showed that a considerable number of fields were cut and shocked prior to maturity and it seemed desirable to investigate the possibility of continued grain development after shocking.

Data obtained from 26 small shocks which were cut before maturity and in which kernel weights were determined at the time of cutting and again after 8 days are given in Table 3. Increases, whether measured in grams or percentages, were highly variable. Samplings were not replicated. It seems significant, however, that every bundle indicated some grain development after cutting.

TABLE 3.—*Kernel weight increases after corn had been cut and shocked.*

| Date of cutting | Dry matter in grain, % | Weight per 100 kernels, grams* | Increases after 8 days in shock† | |
|---|---|---|---|---|
| | | | Grams | % |
| | | Iowa 939 | | |
| Aug. 16 | 42.5 | 17.2 | (a) 3.3 | 19.2 |
| | | | (b) 2.6 | 15.1 |
| Aug. 20 | 45.9 | 19.5 | (a) 3.6 | 18.5 |
| | | | (b) 3.8 | 19.5 |
| Aug. 25 | 55.2 | 24.3 | (a) 1.5 | 6.2 |
| | | | (b) 1.1 | 4.5 |
| Aug. 29 | 60.4 | 25.6 | (a) 1.7 | 6.6 |
| | | | (b) 0.2 | 0.8 |
| | | (Ohio 26 × Ohio 51) | | |
| Sept. 2 | 43.8 | 17.8 | (a) 3.8 | 21.3 |
| | | | (b) 4.1 | 23.0 |
| Sept. 6 | 48.9 | 21.2 | (a) 3.2 | 15.1 |
| | | | (b) 1.2 | 5.7 |
| Sept. 10 | 58.1 | 24.9 | (a) 1.5 | 6.0 |
| | | | (b) 1.3 | 12.0 |
| Sept. 15 | 65.2 | 24.8 | (a) 1.4 | 5.6 |
| | | | (b) 1.6 | 6.4 |
| | | Ohio C 84 | | |
| Sept. 15 | 51.2 | 21.7 | (a) 3.5 | 16.1 |
| | | | (b) 1.3 | 6.0 |
| Sept. 19 | 57.2 | 25.8 | (a) 2.3 | 8.9 |
| | | | (b) 2.7 | 10.5 |
| Sept. 23 | 60.1 | 25.4 | (a) 1.7 | 6.7 |
| | | | (b) 1.2 | 4.7 |
| Sept. 27 | 61.0 | 27.1 | (a) 0.6 | 2.2 |
| | | | (b) 1.4 | 4.9 |
| Oct. 1 | 64.8 | 27.6 | (a) 0.6 | 2.2 |
| | | | (b) 0.5 | 1.8 |

*Ears sampled at time of cutting.

†Same ears as those used to determine weight of 100 kernels (a) sampled again after being in the shock 8 days; (b) ears from duplicate bundle sampled only after 8 days in the shock.

There are two important possibilities of error in the sampling and drying technics. First, during the drying process and because of the higher moisture content, a greater carmelization of sugars might occur in the samples obtained at the time of cutting than in those taken from the same ears 8 days later. This possibility was eliminated when seven sub-samples from a large lot of grain at a high moisture level were dried at different rates, with and without preliminary slow drying periods, and the final weights were found to vary only 0.5%.

Second, it is probable that part of the apparent increases can be attributed to the breaking of kernels in removing those samples taken at the time of cutting, due again to higher moisture than after drying in the shock for 8 days. Careful examination of the kernels in the dried samples, however, did not reveal differential breakage.

It should not be inferred that these data are presented as conclusive evidence that the grain continues to increase in weight after the plants are cut prematurely and shocked at once. The scope of the investigation was too narrow to justify definite conclusions, and the data are presented only because they offer interesting possibilities for future work to obtain a clearer picture of the conditions under which continued grain development may occur.

If such a study is initiated, it should include measurements not only of the changes in the grain, but also the change in the cob and in the remainder of the plant. Chemical analysis of the grain, cob, and plant would be desirable.

## STAGES OF MATURITY AT WHICH CORN IS CUT AND SHOCKED IN OHIO

This phase of the investigation was based upon a survey covering 58 partially cut fields of corn in 19 Ohio counties in 1940 and 1941. Table 4 contains the data. About 30% of the fields in 1940 and 45% in 1941 were partially cut when the survey was made.

TABLE 4.—*Dry matter in the grain of corn when fields were being cut in Ohio, 1940 and 1941.*

| Dry matter in the grain, % | Number of fields sampled | | | Part of maximum yield attained, %* |
|---|---|---|---|---|
| | 1940 | 1941 | Total | |
| 45.1–50.0 | 1 | 2 | 3 | 63–73 |
| 50.1–55.0 | 10 | 5 | 15 | 73–83 |
| 55.1–60.0 | 12 | 11 | 23 | 83–91 |
| 60.1–65.0 | 2 | 13 | 15 | 91–98 |
| 65.1–70.0 | 0 | 2 | 2 | 98–100 |
| Total | 25 | 33 | 58 | |

*Percentage values are from Fig. 4 and are not corrected for increases that may have occurred in the shock.

Harvesting began prior to the time of maximum grain yields in most fields which were cut and shocked. Yield losses, however, cannot be accurately predicted from the grain development curve (Fig. 4)

since the shocking study showed that some grain development probably occurs after cutting.

Some factors which, from the farmer's standpoint, partially offset the yield losses from premature harvesting are (a) available labor is distributed over a longer period of time by starting early, (b) fewer leaves are lost giving a more desirable fodder to feed, and (c) early harvesting permits a more timely preparation of a seedbed for wheat.

It was generally evident from conversations with farmers that they did not know when corn was mature, nor did they realize that substantial yield losses result from premature cutting. Many fields could profitably have been harvested from a week to 10 days later than they were in 1940 and 1941.

## SUMMARY AND CONCLUSIONS

Percentages of dry matter in the grain and kernel weights were measured at 4-day intervals in several corn hybrids during the latter part of their development periods in 1939, 1940, and 1941. The appearances of the ears and ear husks were noted at the time of the later harvests.

In order to determine whether the kernels continued to increase after being cut and shocked, 26 bundles were cut prematurely and the kernel weights were measured before and after drying in the shocks for 8 days.

Partially cut fields of corn were sampled in 1940 and 1941 to determine the stages of development at which corn is generally cut and shocked in Ohio.

The following conclusions are based on the data presented:

1. Corn is not mature until it has reached the maximum dry weight of grain which occurs at about 65% dry matter. Within individual ears maturity is reached at a slightly earlier point.

2. Percentage of dry matter in the grain is the best single criterion of relative and actual maturities in corn within the dry matter range covered by this investigation (30 to 80%). The number of days to mid-silking is the second best criterion, although it was found to be misleading in specific comparisons. A combination of these two criteria, with greater emphasis on the dry matter in the grain probably is most desirable for corn investigators.

3. The time at which the maximum weight per 100 kernels has been reached is not a practicable measure of relative maturity among strains since it involves a series of measurements, and also the endpoint in kernel development is difficult to establish from the curves.

4. Ear appearance is the best practical guide for farmers to cut and shock corn unless moisture testing equipment is readily available. Maximum grain yields are attained when one-third to one-half of the ears are in the ripe stage and the remainder are in the hard dough stage.

5. Plant appearance is not a reliable index of relative or actual maturity.

6. Appreciable development of grain apparently occurs after immature plants are cut and shocked. Additional research is needed to verify this conclusion.

7. Harvesting is started before maximum possible yields of grain are attained in more than 50% of the fields that are cut and shocked in the areas surveyed. Harvesting may profitably be delayed for at least a week in many Ohio fields.

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# DELAYED GERMINATION OR SEED DORMANCY IN VICLAND OATS[1]

Alvin Schwendiman and H. L. Shands[2]

In the fall of 1940 several instances of delayed germination were noted in freshly harvested samples of Vicland oats, a new variety recently described by Stanton (10).[3] Certain samples when tested at room temperature germinated only 65% in two weeks. However, germination was increased to 95% or better when the seed was prechilled. As this variety was about to be released for commercial production,[4] it seemed important to determine the extent and nature of the delayed germination. The immediate need for such a study was occasioned by the necessity of establishing a satisfactory testing procedure for making germination tests in order to judge freshly harvested seed as to requirements for certification.

The main aspects of the physiology of delayed germination in small grains have been reported in the work of Harrington (5) and Johnson (6). Harrington was able to increase the germination of wheat, oats, and barley by artificial drying, opening the coat structures over the embryo with incidental wounding of the scutellum, cutting off the distal end of the caryopsis, removal of the lemma and palea from oats and barley, weakening of the coat structures over the embryo of wheat by the use of sulfuric acid, increasing the oxygen pressure in the atmosphere, and germination at 12° to 16°C.

Johnson (6) was also able to show an increase in the germination of *Avena fatua* by the use of an increased oxygen pressure, lowered germinating temperatures, and by the use of potassium nitrate. Both of these workers are in agreement in stating that the dormant condition is imposed by coat structures impermeable to oxygen.

Johnson (6) considered that the after-ripening process may consist of a series of changes in the tissues of the seed coat which results in an increased permeability to oxygen. Harrington (5) also stated that the improved germination of nonafter-ripened cereals brought about by various treatments appears to result from increasing the permeability of coat structures to oxygen.

Toole (11) and Whitcomb (12) were primarily responsible for the development of the prechilling method for improving the germination of freshly harvested cereals.

Lewis (9) explained the response to low temperatures by nonafter-ripened seed to be most likely a matter of reducing the speed of all processes in germination to that of a limiting factor.

Other phases of the problem of delayed germination in cereals have been dealt with in the literature as indicated by the following conclusions reported in various papers: Cutting immature grain increases the amount of delayed germination (8, 12); low storage temperatures prolong the after-ripening process (6, 8); more delayed germination occurs after cool, wet harvest years (3, 9); more delayed

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[3]Figures in parenthesis refer to "Literature Cited", p. 687.

[4]First released in 1941.

germination is found in the kernels from the basal whorls of *Avena fatua* than from the upper whorls (6); more delayed germination occurs in secondary than in primary seeds (1, 6); all degrees of prompt, slow, and delayed germination are found in varieties of *Avena sativa* (1); delayed germination in *Avena* is inherited as a recessive character (4, 7).

## EXPERIMENTAL METHODS

Unless otherwise indicated, all tests were made by placing two replicates of 100 seeds each between standard germination blotters and reading the test at the end of 14 days. Control or "check" germination tests were made at approximately 22°C. Prechilled tests were made by holding moistened seed at 4°C for 4 days and then placing the seed at 22°C for germination to be completed. The effectiveness of any treatment in breaking the delayed germination is indicated by the increased germination obtained over and above the percentage germination of the control at 22°C. The facilities of the Wisconsin State Seed Laboratory were used in making most tests. Only limited preliminary tests were made in the fall of 1940. All other tests were made with seed of the 1941 and 1942 crops.

## RESULTS

### EFFECTS OF VARIOUS TEMPERATURES AND REMOVAL OF HULLS

Table 1 shows the effects of various temperatures and of the removal of the hulls upon the percentage germination. In this test all

TABLE 1.—*Effect of temperature and of the removal of hulls upon the percentage germination of Vicland oats, all tests started August 19, 1941.*

| Sample No. and Wis. county source | Hulls | Percentage germination after | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 6 days | | 14 days | | | | |
| | | 16°C | 22°C | 4°C* | 8°C | 12°C | 16°C | 22°C |
| 3-Iowa.......... | On | 95 | 83 | 100 | 97 | 98 | 97 | 96 |
| | Off | 97 | 93 | 77 | 81 | 100 | 98 | 98 |
| 9-Dane.......... | On | 71 | 17 | 94 | 93 | 93 | 74 | 43 |
| | Off | 94 | 51 | 99 | 98 | 98 | 98 | 83 |
| 11-Columbia...... | On | 82 | 43 | 90 | 93 | 93 | 84 | 69 |
| | Off | 97 | 85 | 98 | 99 | 97 | 99 | 95 |
| 13-Columbia...... | On | 83 | 23 | 92 | 90 | 91 | 86 | 63 |
| | Off | 97 | 82 | 98 | 98 | 98 | 99 | 95 |
| 14-Sauk.......... | On | 97 | 71 | 98 | 97 | 97 | 98 | 95 |
| | Off | 97 | 97 | 99 | 98 | 97 | 98 | 99 |
| 15-Outagamie..... | On | 91 | 58 | 99 | 96 | 98 | 92 | 90 |
| | Off | 94 | 93 | 96 | 98 | 97 | 96 | 98 |
| 18-Walworth..... | On | 82 | 33 | 95 | 96 | 96 | 89 | 47 |
| | Off | 95 | 71 | 97 | 91 | 97 | 96 | 93 |

*Seeds prechilled for 4 days at 4° C and then placed at 22° C to germinate. All other seeds held constantly at the temperatures indicated.

seeds were rolled in moistened paper towels which were placed in covered enamel trays kept in thermostatically regulated germination chambers. In most cases removal of the hulls increased the rapidity and the percentage of germination. Although removing the hulls gave a fairly satisfactory test after 14 days at all temperatures, this method is laborious. Germination at continuous low temperatures between 8° and 12° C appears to give very satisfactory results without removing the hulls, if a 14-day interval is used. The objections to this method would be the longer time interval required and the need for a continuous low temperature germinating chamber.

Although not indicated in Table 1, the prechilling method allows for complete germination after 8 to 10 days. This method is not only rapid but requires a smaller amount of refrigeration space. If space is very limited, seed to be tested may be placed between moistened filter papers in petri dishes. Best results are secured if the seed is allowed to take up a moderate amount of moisture before the chilling is started. If seeds are either completely dry or excessively wet when chilled, poorer germination may result.

## SEASONAL DURATION OF DELAYED GERMINATION

Fig. 1 shows the seasonal duration of delayed germination in Vicland oats. The reason for the drop in germination of the nonprechilled seeds on December 15, 1941, and January 14, 1942, is not clear, but it appears to have been a real one as it occurred in all nonprechilled replicates. Since the seeds for all germination tests were counted out from bulk lots at the beginning of the experiment and placed under natural storage conditions, progressive selection of the seed could not have been responsible. Since the authors have been able to induce delayed germination in Vicland oats by dry chilling in a refrigerator it is possible that the lower outdoor temperatures during December and January may have been responsible.

In this same study on the seasonal duration of germination, 12 replicates of the same oat sample were planted in soil. Both primary and secondary seeds planted in the soil germinated as well as the seed which had been prechilled. The soil agent responsible for overcoming delayed germination is not known, but it may be soil nitrates as indicated later.

## DELAYED GERMINATION IN RELATION TO PANICLE POSITION

Table 2 shows that in Vicland oats there is more delayed germination in the secondary seeds borne on the basal panicle whorls than in the secondary seeds of the upper whorls. This relationship does not hold for the primary seeds. While State's Pride oats shows a marked effect of the date of harvest upon the amount of delayed germination in the secondary seeds, this is not true for Vicland. This same test was repeated in the fall of 1942 using both Vicland and State's Pride oats harvested on July 8, July 17, and July 22, but germination was immediate for all kernels of both varieties.

Though these results when taken alone are not conclusive, they are in agreement with Johnson's (6) findings that *Avena fatua* seeds hav-

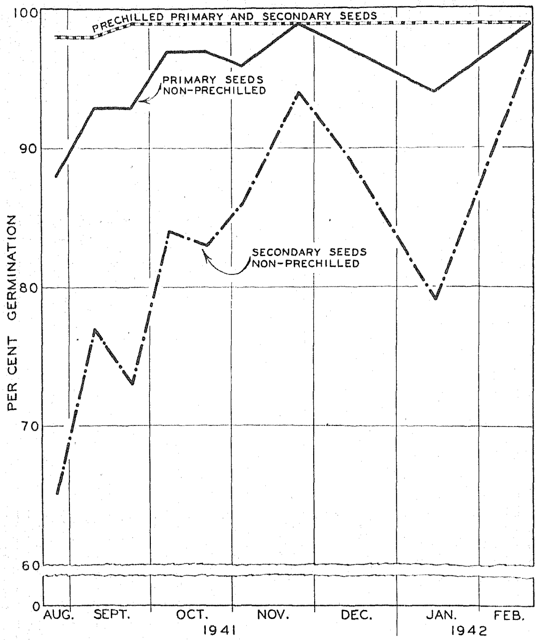


FIG. 1.—Extent and duration of delayed germination in Vicland oats as shown by the germination of prechilled and nonprechilled seeds. The percentages of germination for prechilling are the averages of 12 replicates of 100 seeds each; for the nonprechilled seeds, the averages of 6 replicates of 100 seeds each.

ing a basal panicle position exhibit more delayed germination than seeds having a terminal position. More delayed germination in prematurely cut oats is also in agreement with the work of Whitcomb (12) and Larson, *et al.* (8).

### EFFECT OF CHEMICAL TREATMENTS

Table 3 shows the effect of various chemicals upon the germination of a sample of oats exhibiting delayed germination. All nitrates, whether used for presoaking the seeds or for moistening blotters, were effective in increasing the germination. The use of ammonium nitrate,

TABLE 2.—*Delayed germination in relation to panicle position and date of harvest for Vicland and State's Pride Oats, test started Sept. 4, 1941, and read Sept. 18.*

| Treatment | Panicle whorls | Percentage germination | | | |
|---|---|---|---|---|---|
| | | July 15 harvest | | July 21 harvest | |
| | | Primary | Secondary | Primary | Secondary |
| | | Vicland | | | |
| 22°C | Upper | 100 | 94 | 99 | 89 |
| | Central | 100 | 80 | 99 | 83 |
| | Basal | 99 | 82 | 98 | 79 |
| Prechilled | Upper | 100 | 100 | 100 | 100 |
| | Central | 100 | 100 | 99 | 100 |
| | Basal | 98 | 99 | 100 | 98 |
| Soil test | Upper | 98 | 95 | 98 | 98 |
| | Central | 96 | 100 | 98 | 96 |
| | Basal | 94 | 93 | 89 | 93 |
| | | State's Pride | | | |
| 22°C | Entire panicle | 95 | 40 | 100 | 91 |
| Prechilled | Entire panicle | 100 | 99 | 100 | 100 |
| Soil test | Entire panicle | 95 | 96 | 93 | 97 |

although giving a high germination, definitely retards the elongation of the roots and the first internode and coleoptile for the first 8 to 10 days. Subsequent tests using the same concentration of the chloride salts of calcium, potassium, and ammonium, indicate that the germination increase is attributable to the nitrate and not to a simple salt effect.

TABLE 3.—*Effects of various chemicals upon the germination of secondary seeds of Vicland oats, two replicates of 50 seeds each placed between blotters at 22°C, all tests started Sept. 8, 1942.*

| Treatments | Percentage of seeds with coleoptiles seed length or longer | | |
|---|---|---|---|
| | 4 days | 8 days | 14 days |
| Blotters moistened with water | 50 | 82 | 86 |
| Blotters moistened with a 0.2% solution of $KNO_3$ | 65 | 98 | 100 |
| Seeds soaked 1 hour in a 2% solution of $KNO_3$ | 76 | 96 | 97 |
| Blotters moistened with a 0.2% solution of $Ca(NO_3)_2$ | 54 | 100 | 100 |
| Seeds soaked 1 hour in a 2% solution of $Ca(NO_3)_2$ | 86 | 98 | 100 |
| Blotters moistened with a 0.2% solution of $NH_4NO_3$ | 73 | 99 | 98 |
| Seeds soaked 1 hour in 2% solution of $NH_4NO_3$ | 85 | 98 | 100 |

A comparison was made of the effects of prechilling and using a 0.2% potassium nitrate solution to moisten the germination blotters. From Table 4 it appears that the use of nitrates was equally as effective in overcoming delayed germination as was prechilling. Ordinarily, when seed is prechilled for 4 days, a total of about 10 days is required before germination can be read. However, when potassium nitrate is used the test can be read after 6 to 8 days. The low germination for sample No. 2 is an example of cases which occasionally occur following prechilling. In no case has a lowered germination resulted from the use of dilute potassium nitrate.

TABLE 4.—*A comparison of the effects of normal laboratory germination, prechilling, and the use of a 0.2% solution of potassium nitrate upon the germination of samples of Vicland oats showing marked dormancy.*

| Sample No. | Date of test | Percentage germination after 14 days | | |
|---|---|---|---|---|
| | | Blotters moistened with water | Seed prechilled | Blotters moistened with $KNO_3$ |
| 92 | Nov. 10, 1941 | 68 | 88 | 99 |
| 94 | Nov. 16, 1941 | 80 | 98 | 98 |
| 149 | Nov. 31, 1941 | 58 | 87 | 86 |
| 186 | Dec. 11, 1941 | 79 | 91 | 99 |
| 191 | Dec. 14, 1941 | 80 | 99 | 99 |
| 195 | Dec. 15, 1941 | 72 | 98 | 97 |
| 196 | Nov. 15, 1941 | 83 | 96 | 99 |
| 197 | Nov. 15, 1941 | 72 | 99 | 97 |
| 206 | Nov. 18, 1941 | 70 | 95 | 95 |
| 207 | Nov. 19, 1941 | 60 | 97 | 95 |
| 1 | Aug. 18, 1942 | 51 | 87 | 98 |
| 2 | Aug. 18, 1942 | 45 | 39 | 99 |
| 3 | Aug. 18, 1942 | 61 | 99 | 96 |

## DISCUSSION

The results obtained from these tests demonstrate that delayed germination in Vicland oats is a laboratory problem and not one affecting germination in the field. From the practical viewpoint delayed germination may prove very desirable in wet harvest seasons in preventing sprouting in the shock. Deming and Robertson (2) found considerable delayed germination in Kanota oats (*Avena byzantina*) in the laboratory and also observed that this variety sprouted less in the shock than did other varieties without delayed germination. During the wet harvest season of 1942 there were some observations of less sprouting in Vicland oats than in other varieties.

The results presented in this paper suggest no basis for explaining the wide variations which occur in the degree of delayed germination found in various samples of Vicland oats. Although immaturely harvested oats may exhibit more dormancy in some varieties, this does not seem to have been the case with Vicland in 1941 or 1942. Very little information is available to show how local environmental conditions may influence the development of the delayed germination characteristic.

With one exception (6) there have been no previous reports of the possibility of using nitrates in place of prechilling to overcome delayed germination in oats or other grains. This substitution of methods appears entirely feasible, but further observations will be desirable before any conclusive statement can be made. Johnson (6) has suggested that the stimulation by potassium nitrate might be considered to result from a direct germinative stimulation by the absorbed anion, from indirect effects of the absorbed anion such as, for example, increased utilization of stored carbohydrates, or from chemical effects upon the seed coat which produce increased permeability to oxygen.

## SUMMARY

Laboratory and soil germination tests were made to determine the extent and nature of delayed germination in Vicland oats. Many samples when tested under normal germination procedures in August and September gave only 40 to 60% germination after two weeks.

Removing the hulls greatly increased the rate and the total percentage germination. Germination at continuous low temperatures between 8° and 12° C gave satisfactory tests after 10 to 14 days without removing the hulls. A rapid and satisfactory test was secured by prechilling the moistened seed for 4 days at 4° C and then placing it at 22° C for 6 days.

Tests made at intervals of two weeks to a month between August 1941 and February 1942 indicate that delayed germination in Vicland oats under natural storage conditions is overcome by February of the year following harvest.

Secondary seeds showed more delayed germination than primary seeds. Some evidence was found to indicate that seeds having a basal position in the panicle show more dormancy than oats in terminal positions. No definite relationship was noted between stage of maturity at harvest and degree of dormancy.

The use of a 0.2% solution of potassium nitrate for moistening the germination blotters appeared to be equally as effective as prechilling in overcoming delayed germination.

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# INSECT RESISTANCE IN CORN[1]

John H. Bigger[2]

THE gradual changes of agricultural practices which have been made by American farmers during the past three-quarters of a century have greatly altered insect control programs necessary to the economical production of corn in the Corn Belt area. The entire ecological picture has been changed. The environment to which the insect is exposed today is quite different from that existent during the middle of the last century. Much of the change has taken place during our lifetime, yet this is a fundamental concept which has not received the attention to which it is entitled.

Most of the insects with which we are now concerned were present prior to the start of agricultural development in the midwest. They were, however, generally restrained by their environment and natural enemies. When the original prairie sod was broken for the planting of corn, the soil was in a highly fertile condition, and the resulting crops grew rapidly and strongly. The resultant of these two conditions was a minimum of loss resulting from insect damage.

Repeated growth of corn or the use of corn-oats or corn-oats-timothy rotations produced an entirely new set of conditions at the close of the last century and the early years of the present century. Insects which are natural feeders on the *Graminae* had taken full advantage of the increase in the presence of the full-season and continuous feeding areas that were an integral part of the new agricultural program. Natural enemies, such as birds, skunks, and snakes, had been reduced in numbers. Soil fertility had suffered. The net result was a rather rapid build-up of such insects as white grubs, *Phyllophaga* spp., wireworms, Elateridae, the corn rootworm, *Diabrotica longicornis* Say., corn root aphids, *Anuraphis maidiradicis* Forbes, and chinch bugs, *Blissus leucopterus* Say., and severe crop losses due to attacks by these insects. The grape colaspis, *Colaspis brunnea* Fab., also appeared sporadically during this period.

About the time that this situation became really serious, legumes were rather generally introduced into rotations. Farmers began to use red clover and later sweet clover more intensively and with a purpose. In fact, two purposes were served, *viz.*, the change served at least partially to recoup the losses in soil organic matter and fertility and it served to break up the continuous grass sequence. The entomological picture was entirely altered. Here was a new ecological situation. This change served to reduce, at least partially, losses from the grass-feeding insects. By the third decade of the present century these insects were considered to be at least partially controllable by rotation with clovers. However, the general trend of fertility downward was not entirely checked, even by the introduction

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of sweet clover, so that the corn plants were less able to withstand insect feeding and the problem of control became increasingly difficult. Changes in certain tillage practices have been introduced, but have failed to change the trend.

Other changes of wide significance have occurred in the insect picture. During recent years we find such insects as the southern corn rootworm, *Diabrotica duodecimpunctata* F., which is more or less a general feeder, playing an increasingly important role. These insects are not amenable to control by rotation and not readily or completely controlled by tillage practices. The grape colaspis has reappeared as a perennial problem on corn and soybeans. The soybean has become one of its principal food plants and the immense increase in soybean acreage may be the reason for this situation. It is only partially controlled by rotation or tillage practices.

Two other common insects that have greatly affected our Corn Belt economy are grasshoppers (Locustidae) and the corn earworm, *Heliothis armigera Hbn.*, neither of which is materially affected by cultural practices commonly followed in the great corn-growing area of the country.

None of the insects so far brought into the picture is new to our agriculture. They have simply taken advantage of changes in cultural practices which reacted in their favor. But in the meantime new insects have been introduced and become firmly established in the Corn Belt. Of these the one which commands our immediate attention is the European corn borer, *Pyrausta nubilalis* Hbn. This insect is somewhat, but not completely controllable by cultural or tillage practices that are economically possible. The Japanese beetle, *Popillia japonica* Newm., is a present threat, but still to be dealt with.

In the meantime another factor, not yet considered in the development of our corn economy, is the appearance and widespread adoption of control-pollinated or hybrid corn. This has had a material effect upon the insect picture. The genetic complex of the corn plant has been sorted into various combinations different from those of the original plant from which the inbred lines bearing these various combinations of genes was produced. There have been developed large numbers of inbred lines among which there is, at least in some cases, a greater range of susceptibility or resistance to insect attack by certain insects than was present in the original parent material. It has been suggested that this is the direct cause of the apparent increase in damage by the corn leaf aphid, *Aphis maidis* Fitch, during the past 5 to 8 years.

From the foregoing it might appear that the control of insects attacking corn has arrived at an impasse. It is not intended that such a conclusion be arrived at, but rather to point out that changing conditions have altered the corn-insect picture to the extent that practices which have in the past given entirely satisfactory insect control are not now entirely effective. This in itself would serve to indicate the necessity for a different and newer attack on the problem, which brings us to the point of the present dissertation, the use of insect resistant strains, varieties, or hybrids of corn for corn crop production.

The use of insect-resistant or tolerant strains is not new. This biological approach to the insect control problem in the development of efficient agricultural production has been known and advocated since Havens (6),[3] in 1792, published an item regarding the Hessian fly resistance of the Underhill variety of wheat. However, the possibility of the use of this agency in preventing damage to corn did not come to the fore until 1917, when certain open-pollinated varieties of corn were found to be resistant to, or tolerant of, the attack of the second brood of chinch bugs (5).

Soon after that came the development of the use of inbred lines of corn to produce commercially available hybrids satisfactory for the farmer to use. This put a new tool into the hands of investigators searching for some way to defeat the ever-increasing inroads of insects upon the corn crop.

The wide range in the genetic complex of inbred lines of corn was known. It was also recognized that they varied widely in their resistance or susceptibility to plant diseases. It was soon found that they also varied in their relative susceptibility or resistance to insect attack.

This knowledge was first put to use in the attack on the European corn borer problem. As early as 1924 tests of varieties had shown marked variation in the borer population between varieties of the same maturity and height grown in closely adjacent plots in Ohio (10). In 1927 tests of 252 crosses between inbred lines were carried out. Since then, wide-scale tests of inbred lines of corn have been made in Ohio, Indiana, Michigan, and, in 1942, in Illinois, by various state and federal workers in closely cooperative programs between entomologists and plant breeders. As a result, there can no longer be any doubt that there exists germ plasm which possesses the quality of resistance to European corn borer, in the area where a single brood predominates, that it is present in some of our inbred corn lines, and that it is transmitted to the progeny of such lines. This resistance has been ascribed to simple Mendelian dominant factors by some, but the most recent and complete report by Patch (12) states that, "The cumulative effect of an undetermined number of mutiple factors in inbred lines in producing borer resistance in hybrids is clearly indicated." We have seen further evidence in Illinois in 1942 which tends to corroborate the statement by Patch. This information has become widely known and has been applied in production programs in areas where the insect is an economic factor in corn production.

Shortly after this work was started it was possible to make satisfactory tests of the relative reactions of inbred lines to the attack of second brood chinch bugs. This work started in the early 1930's in the breeding plots of J. R. Holbert at Bloomington, Ill. (8, 9). The work of Holbert in Illinois in cooperation with the Illinois entomologists and that of Snelling and Dahms (13) in Oklahoma and of Painter and Brunson (11) in Kansas showed that inbred lines of corn existed at that time which transmitted to their progeny a high degree of resistance to second brood chinch bugs, and it was indicated (8)

[3]Figures in parenthesis refer to "Literature Cited", p. 693.

that ". . . . . some inbred lines carry dominant factors for chinch bug resistance, while other inbred lines carry dominant factors for susceptibility." Since that time standard inbred lines have been pretty well catalogued and new inbred lines developed which have been shown to carry chinch bug resistance factors and to transmit them to their progeny. This information has been put to practical use by seedsmen who are producing hybrids for the use of farmers in the chinch bug infested areas.

In the meantime, work has progressed toward studies of the relative resistance or susceptibility of inbred lines of corn to various other insects. Among these the corn leaf aphid holds a prominent place. Since 1937, the relative abundance on, and damage to, inbred lines by this insect has been studied intensively in Ohio, Indiana, Wisconsin, and Illinois. It has been shown (14) that great variations exist in the resistance and susceptibility of inbred lines of corn to the corn leaf aphid. Further, it has been shown that the aphid reactions of many of the lines are transmitted to their single crosses. This information is known to seedsmen and is being put to practical use.

Progress has also been made in determining the relative resistance or susceptibility of inbred lines of corn to attack of the corn earworm. An intensive study of this problem has been in progress since the assignment of R. A. Blanchard to it in 1937. Inbred lines and their crosses have been studied in an area extending over the central and southern states. The studies show (3) that, "Some inbred lines tend to be consistently resistant, whereas others are definitely susceptible," and further that ". . . . resistance to the corn earworm is inherited." It is also shown that "Some inbred lines transmitted a high degree of resistance even when combined in single crosses with susceptible lines," and that "Some inbred lines were stable in their resistance or susceptibility at the different localities included in this study." Progress is being made in the development of new inbred lines carrying germ plasm which is highly resistant to the corn earworm.

The southern corn rootworm has also received considerable study (1) at various stations in the Corn Belt since 1937. The most comprehensive work that has been reported was carried on in Illinois since R. O. Snelling has been stationed there for the purpose of resistance studies. More than 60 inbred lines with yellow endosperm and about 30 lines with white endosperm were studied as lines and in single crosses. The results of this study have been reported (2) and showed a marked differential in response of the plants to attack by the larvae of this insect. One inbred line was outstanding in its resistance to lodging following the attack. This resistance is shown to be heritable. There is unreported work at the Illinois Experiment Station which indicates a definite morphological effect upon the larvae of this insect when they feed upon selected inbred lines of corn.

Grasshoppers have received their share of study, especially in Kansas. Brunson and Painter (4) studied the comparative damage to corn strains during the 1936 outbreak in Kansas. They report that, ". . . . outstanding instances of differential injury among corn varieties, top crosses, and hybrids were noted." They state also that, "As a rule, the varieties and inbred lines of corn showing the greatest

resistance originated in areas where grasshoppers are a natural environment," which is a definitely significant statement and worthy of attention from other workers. Greenhouse studies carried on at Illinois during the period 1938–40, and not yet published, show that hoppers of the species *Melanoplus differentialis* (Thos.) show distinct preference for certain inbred lines when given choice, and further, that feeding of the hoppers on different lines has a definite effect upon the development of these hoppers throughout their life.

In 1941, Hoegemeyer (7) had an opportunity to make some observations relative to white grub resistance in Kansas. He found that single-cross and double-cross combinations of corn differed significantly in the percentage of plants root lodged and that these differences seemed to be a manifestation of differences in root injury by these insects. He states that, "The single crosses having the least root injury when combined gave the double cross combinations which were least injured, whereas, the more severely damaged single crosses in combination gave double crosses which were more severely damaged by white grubs."

Some studies have been made concerning the resistance of inbred lines to stored grain insects. These have not been published but indicate the possibility of the use of this characteristic in the production of commercial corn hybrids.

There may be work in progress with other insects which has not come to the writer's attention, or has not been published. The foregoing is a brief summary of major accomplishments to date. The job is far from complete. Certain insects, such as the grape colaspis and the seed corn maggot, *Hylemyia cilicrura* Rond., have not been studied. The European corn borer must be restudied with reference to resistance to the two-brooded area. Wireworms have not been touched. Neither has this problem been thoroughly studied with reference to the morphology and physiology of the plant in its relation to the resistance of the plant. The effect of feeding on the various lines upon the morphology and physiology of the insect has only been touched. The work done has all been elementary and a big job is still ahead in which it is essential that entomologists, plant breeders, agronomists, physiologists, chemists, and possibly other specialists must cooperate before the problem of the plant-insect relation can be fully understood.

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# INSECT RESISTANCE IN WHEAT[1]

ELMER T. JONES[2]

AMONG the methods of preventing losses caused by the insect pests of growing wheat, the breeding of insect-resistant varieties now appears to be one of the most promising, and the following discussion relates largely to methods that have been or are being used to produce varieties resistant to the hessian fly, *Phytophaga destructor* (Say).

## REVIEW OF LITERATURE

The earliest recorded observation of hessian fly resistance in wheat was made by Isaac Underhill near Flushing, Long Island, in 1782 (1, 8, 12).[3] This resistant wheat was described as a hard-stemmed, yellow-bearded variety, which was subsequently given the name of Underhill. Packard (21) stated that, "Of the different varieties of fly-proof wheat, the Underhill variety has for nearly a century been highly recommended."

Chapman (8), in 1778, besides recommending a resistant variety of wheat, advocated late sowing as a precaution against fall fly attack and the planting of varieties of quick, vigorous growth against spring attack. This is perhaps the first observation on the desirability of delayed seeding, the most practical method of general fall fly control in use today. Delayed seeding, however, is ineffective under some adverse seasonal conditions and involves a disadvantageous agronomic practice. There is no known control of the spring brood of flies except the use of resistant varieties.

In the earliest references to "fly-proof" wheat, Underhill, Lancaster, Lawler, and White Flint are mentioned frequently. In later accounts, China, Clawson, Mediterranean, Red Chaff, Red May, and Fultz occur often.

Woodworth (37) is credited with making the first systematic study of the variations in fly resistance. He examined 125 varieties of wheat being grown at Berkeley by the California Agricultural Experiment Station, classified them into three groups according to degree of resistance or susceptibility, and also called attention to the fly resistance of durum wheat. Roberts, *et al.* (30) and Gossard and Houser (13), in resistance tests in New York and Ohio, found that vigorous-growing, strong-strawed varieties were less liable to injury by the fly than slow-growing, weak-strawed varieties and found little evidence to support the idea of immune varieties. Dawson was found resistant in many counties of New York, and susceptible in Canada and Ohio.

In the years following, many papers on fly-resistance studies appeared, notable

[1]Contribution from the Bureau of Entomology and Plant Quarantine, Agricultural Research Administration, U. S. Dept. of Agriculture. Presented as part of a symposium on "Insect Resistance in Farm Crops" at the annual meeting of the Society held in St. Louis, Mo., November 10 to 12, 1942. Received for publication March 9, 1943.

[2]Assistant Entomologist. The writer is indebted to the many workers who have contributed information and suggestions for the preparation of this paper. Investigations reported herein concerning wheat breeding in the Kansas and central wheat-breeding area were conducted cooperatively by the Bureaus of Entomology and Plant Quarantine and Plant Industry of the U. S. Dept. of Agriculture and the Departments of Entomology, Agronomy, and Botany of the Kansas State Agricultural Experiment Station.

[3]Figures in parenthesis refer to "Literature Cited", p. 702.

among which are those by McColloch and Salmon (19), Haseman and McLane (15), Packard (22), and Painter, *et al.* (26). McColloch's early work in particular stimulated new interest in breeding fly-resistant wheat. The wide extent of researches on the hessian fly is emphasized by the fact that Wade (34) published a bibliography of 1,256 titles on the fly, including many on the subject of resistance. In 1941 Snelling (32), Packard (23), Platt and Farstad (29) published papers containing extensive reviews of fly and wheat-insect resistance.

Many of the papers that appeared during the period from 1891 to 1931 tend to confirm the observations of earlier workers that fly immunity in the ordinary varieties of winter wheats does not exist, although such varieties as Dawson, Honor, Illini Chief, Fulhard, Michigan Wonder, Red Rock, and others may possess a high degree of resistance in some environments; and that such characters as vigor of growth, stiff, hard straw, earliness, and tight sheaths may be important factors in reducing fly damage.

Painter, in 1932, isolated a resistant strain of Marquillo and successfully transferred fly resistance from this spring wheat to five varieties of common winter wheat (25). The resistance derived from Marquillo appeared to be recessive and due to more than one genetic factor. Though showing only mild resistance under epidemic conditions of infestation in Indiana and in some eastern states, selected hybrids under similar conditions of infestation in tests in Kansas and Missouri were much more resistant than common winter wheats.

Caldwell and Compton (5) found Illinois No. 1 W38 in 1935 to be more highly resistant than Marquillo in Indiana, and durum wheat F. P. I. 94587 to approach immunity to infestation. These varieties and a few selected hybrids with common winter wheats have been tested in cooperative uniform nurseries over a period of years in a number of widely separated states and have been found to develop little or no infestation.

Cartwright and Wiebe (7) crossed Dawson C. I. 3342, found to be resistant to the fly in California, with two susceptible wheats, Big Club C. I. 11761 and Poso C. I. 8891. From a study of the classification of the $F_2$ lines based on the infestation behavior in $F_3$ rows, a ratio of 15 resistant to 1 susceptible was obtained. It was concluded that in these crosses, under the conditions of the experiments, the resistance of Dawson was controlled by two genetic factors. Thus, for the first time, the inheritance of resistance was established on a factorial basis.

Noble, *et al.* (20) found that infestations of $F_2$ populations of crosses Dawson ×Illinois No. 1 W38 and Dawson×Illinois No. 1×(Norka×Carina) averaged higher than had Dawson×Poso $F_2$ in previous studies. The data indicated that for fly resistance Illinois No. 1 W38 and Illinois No. 1×(Norka×Carina) were better than Dawson by at least one factor.

## SOURCES OF FLY RESISTANCE

With the exception of Dawson, Kawvale, and a few other varieties and strains locally resistant to the fly in some sections, commercially grown common winter wheats, because of their variable reaction to infestation, appear to have only incidental value as fly-resistant parentals. All available American winter wheats have been tested for fly resistance at several points in the central wheat-producing states by federal entomologists and all have been found susceptible in one or more tests. Selections from several white winter wheats from Turkey have recently been made in Indiana by W. B. Cartwright. So

far these selections from the Turkish varieties have shown a high degree of resistance in tests against heavy fly infestations.

In the cooperative fly-resistance work of the Bureaus of Entomology and Plant Quarantine and Plant Industry of the U. S. Dept. of Agriculture and the Departments of Entomology, Botany, and Agronomy of the California, Kansas, Indiana, and Pennsylvania Agricultural Experiment Stations, most available foreign plant introductions, principally spring wheats, have been tested for fly reaction under conditions of heavy infestation in the greenhouse and in widely distributed outdoor test plots. The records are unpublished, but they show that over 25 of these foreign varieties and strains of spring wheat have a degree of fly resistance approaching or exceeding the American spring wheats, Marquillo, Illinois No. 1 W38, Java C. I. 10051, Dixon C. I. 6849, and Marvel C. I. 8876. Others, reported by Bayles and Taylor (3) and by Cartwright, *et al.* (6), show promise of producing highly resistant lines if reselected. With the exception of Dawson and Kawvale, all the resistant varieties yet found possess too many undesirable characteristics to be of use except for transmitting fly resistance when crossed with adapted varieties.

Analysis of the resistance reaction of many selections and crosses indicate that the many resistant strains now available appear to fall into about five levels of fly resistance, namely, (a) the limited general resistance of Dawson and Kawvale, except that in California Dawson is more resistant than Illinois No. 1 W38 and that in parts of Kansas Kawvale is highly resistant; (b) the medium resistance of Marquillo; (c) the high resistance of Illinois No. 1 W38, Java, Uruguay selections, and Marvel spring wheats; (d) the apparently somewhat higher resistance of certain white winter wheat selections from Turkey when tested in Indiana and Dawson in California; and (e) the near immunity found in P. I. 94587 durum and perhaps other wheats of lower chromosome number.

In California Dawson has been successfully used as a source of superior resistance, but in the central and eastern states it has been necessary to resort to the spring wheats for sufficient resistance to insure adequate fly protection. Marquillo, which transmits effective resistance to the fly in Kansas and Missouri, exhibits lower resistance east of the Mississippi River, where the relatively higher resistance of Illinois No. 1 W38 is required. Winter selections from hybrids of Uruguay wheat selections, IVy (Gelou) C. I. 12001, IVCI + No. C. I. 12034, and Renacimiento, seem to be better adapted in Kansas and Missouri than those from hybrids of Illinois No. 1 W38. The durum P. I. 94587 gives some evidence of transmitting near immunity to the fly to its winter hybrids, but also produces sterility and poor types in many of them. A few of the better types have been selected. As in most species hybrids, backcrossing and reselection will be required to produce desirable fly-immune strains. Some of the winter hybrids with fly resistance transferred from spring wheats may lack superior winter hardiness, which is being added by further crossing and selection. The white, winter selections from Turkey with high fly resistance have advantages over the spring wheats of winter habit and ability to tiller. Weak straw, disease susceptibility, low yield,

white grain, unknown milling quality, and lack of adaptation are undesirable characteristics of some of their hybrids which may be overcome by a backcross program.

Plant breeders, entomologists, and pathologists at several stations have successfully combined the various types of fly resistance with resistance to disease in good, adapted varieties of winter wheat. Some of these strains show promise of being equal or superior to many of the commonly grown susceptible varieties, even when these latter are not infested.

## BREEDING NEW RESISTANT VARIETIES

Requirements for breeding fly-resistant wheat varieties vary with the area where they are to be grown. Different methods of breeding have been used partly because of differences in the philosophy of the breeder and partly because of differences in area, types of wheat, and races of the fly. In California, where comparatively few varieties are needed and standard types are generally acceptable, the backcross method described by Briggs (4) apparently is best suited for breeding fly- and disease-resistant varieties. Workers in California have successfully transferred commercially valuable fly resistance to two club wheats, Poso and Big Club.

The backcross breeding program to produce fly-resistant varieties of wheat for California was planned and undertaken by W. B. Cartwright and G. A. Wiebe. This program called for crossing Dawson to Poso and Big Club and making five successive backcrosses of fly-resistant segregating hybrids to the susceptible parent in order to recover Poso and Big Club agronomic types. From $F_3$ of the last backcrosses, lines homozygous for fly resistance and agronomic type are composited. Such breeding theoretically should result in new varieties having approximately 98.5% of the characteristics of the recurring parent.

In Kansas and Indiana and throughout the winter-wheat areas of the Middle West and East, where many varieties of hard and soft wheats are grown and the prevalent commercial types need to be improved in many ways, the breeding for fly and disease resistance is complicated. Many strains of wheat must be tested for fly and disease reaction in several environments. A large number of simple and complex crosses, some backcrosses, and a great amount of testing of pedigreed lines are used to combine in one variety resistance to different races of the fly—presumably only one race occurs in California—and fungous diseases with the ideal type of wheat for a given locality.

In Kansas workers of all agencies engaged in wheat improvement meet to formulate joint plans and to determine what crosses should be made and how, when, and where the progeny should be grown in the various test plots. This avoids duplication, allows full advantage to be taken of all materials, and results in the best possible combinations of desirable characteristics in a single hybrid with a minimum of wasted effort.

The continuous-selection-pedigree method is used for selecting resistant parentals and hybrids through $F_6$. Seed of $F_2$ to $F_5$ generations

is divided and planted in spaced rows in several nurseries, where the plants are subjected to different pests for the purpose of eliminating the undesirable strains. Strains susceptible to the hessian fly are dropped at harvest on the basis of their reaction to fall infestation. Selected rows are pulled, examined in the laboratory, and disposed of according to reaction to spring fly infestation. Selections are rotated, passing through a successive series of nurseries until all types of resistance are fixed and undesirable characteristics are eliminated.

During 8 years of cooperative work at the Kansas Agricultural Experiment Station approximately 10,000 strains, principally varietal and hybrid selections, including most known varieties and species of wheat, have been studied for fly reaction, at one time or another, in the experiment station fly-test nurseries and in one or more of the similar nurseries that have been conducted for various periods at Wichita, Manhattan, Parsons, Ramona, Bennington, and Junction City, Kans., and at Springfield, Mo. At present, nurseries are located at Manhattan and Bennington, Kans., and Springfield, Mo. The Bennington nursery is useful in studying the reaction of plants to the strain of flies prevalent in the area where hard wheat is grown. Plots have been sown at Springfield since 1912 for tests of wheats against the strain of flies prevalent in the soft-wheat area, with scarcely a break in high fly populations. Constant heavy infestations have made the Springfield records particularly valuable in interpretating infestation reactions in other test nurseries.

Several varieties possessing limited fly resistance have been released. Kawvale was approved in 1931 and released to growers in Kansas in 1932. Because of its resistance to the fly in the extreme western portion of the soft-wheat area, and to loose smut and rusts, it now leads all other wheat varieties in acreage in eastern Kansas. In 1941, partly on account of its Kawvale type of fly resistance and high yield, Pawnee (Kawvale×Tenmarq C. I. 11669) was approved for distribution in Nebraska and is being increased by the Kansas Station. Experimental plantings of Pawnee in the hard-wheat area have shown commercially valuable resistance to the fly.

Big Club 38, a fly-resistant strain developed by Noble and Suneson, was released experimentally in California in 1938 after the third backcross of Dawson×Big Club to Big Club. No damage to this variety has occurred in field test plots during the last 4 years, while nearby fields of ordinary Big Club were visibly damaged by infestations of the fly in from 50 to 98% of the plants. A new fly-resistant composite, Poso 41, involving Dawson×Poso, is being increased for release in California in 1942, and the final crosses involving Dawson×Big Club will be tested in 1943, when lines homozygous for resistance to the hessian fly, bunt, and stem rust will be selected for compositing and release.

During the last 15 years there has been a steady advancement toward the ultimate production of good varieties of wheat possessing resistance not only to the hessian fly but also to the most common fungous diseases, including stem rust, leaf rust, bunt, and scab. Through the combined efforts of many workers, numerous sources of fly resistance have been found, and this character has been success-

fully transferred to desirable varieties of commercial wheat. Although progress is necessarily slow, owing to the vast amount of crossing, selecting, and testing involved, the results already obtained and in prospect are encouraging.

## RESISTANCE TO OTHER INSECTS

Varieties of wheat have been reported resistant or tolerant to attack by at least 15 insects besides the hessian fly. These insects include the wheat stem sawfly, the wheat stem maggot, grasshoppers, wireworms, the "green grain bug," tipulids, flea beetles, the frit fly, the wheat midge, the wheat stem sawfly, the wheat jointworm, the wheat strawworm, the green bug, and the chinch bug. Breeding for resistance to the wheat stem sawfly is being conducted in Pennsylvania and Canada and for resistance to grasshoppers in the Dakotas and Canada, but with the exception of the work on the hessian fly, little or no extensive testing and breeding to develop resistance to the other insects have been reported.

Durum wheats are generally more resistant to attack by the wheat stem sawfly than varieties of common wheat. Kemp (18) found in 1931 that certain solid-stem varieties of wheat were resistant to attack by this sawfly and suggested that the solid-stem factor be incorporated in certain northern commercial wheats. In correspondence Udine[4] states that workers at the Carlisle, Pa., laboratory of the U. S. Dept. of Agriculture, Agricultural Research Administration, Bureau of Entomology and Plant Quarantine, have established the fact that wheat sawflies have difficulty in maturing in solid-stem wheats. He writes that, "The solid-stem wheats available were of spring habit and were, therefore, not suitable to conditions in the Middle Atlantic States. With the aid of Dr. C. F. Noll at Pennsylvania State College, crosses were made to bring the factor of solid stemness into desirable winter wheats."

Examination of the $F_4$ generation indicates that solid stemness has apparently been bred into winter wheats. Farstad (11), in studying the nature of sawfly resistance, observed that whenever pith tissue completely filled the lumen of the stem it appeared to constitute a mechanical barrier to the movement of the larvae, and that firm, compact, pithy tissue prevented the larvae from feeding.

Platt (27) found that three partly dominant factors control the expression of hollowness. Solid stem appeared to be influenced by certain environmental conditions in Vulgare wheats, whereas environment had little effect on a solid-strawed durum variety, Golden Ball. Platt, *et al.* (28) crossed solid-stem selections, resistant to the sawfly, with Thatcher and Renown. Studies of the segregating generations showed that solid stems and beards are associated in the cross Renown×S615–9 but not in the Thatcher×S615–11 cross. Neither stem rust nor glume color was associated with solid stems.

Webster (36) found the variety Velvet Chaff to be more highly infested with the wheat stem maggot than Michigan Wonder. Dunham (10), reporting on 4 years' work with a number of spring-wheat

[4]E. J. Udine, U. S. Dept. Agr., Bur. Ent. and Plant Quar., Sept. 19, 1942.

varieties, found Ceres, Hope, and Supreme to be more resistant to stem maggot damage than Reward or Thatcher. Resistance was influenced by seasonal conditions.

For a number of years Allen and Painter (2) observed the reactions of winter wheats to both spring and fall maggot injury. Infestations of the varieties Turkey, Red Rock, Blackhull, and Beechwood were consistently high in all tests. Other varieties, such as Honor, Dawson, Harvest Queen, Tenmarq, and Minturki, had relatively low infestations in all tests. Time of heading was found to be important. Late planting of early varieties, for example, Early Blackhull, may completely reverse the resistance action.

Clark (9, page 223) reported Ceres wheat to be less damaged by grasshoppers than other varieties grown in North Dakota. The durum wheats appear to be particularly susceptible to grasshopper attack. The writer, in 1937, observed four randomly replicated rows of Iumillo and of P. I. 94587 to be completely stripped by a heavy infestation of grasshoppers, whereas 100 rows of spring and winter wheats in the same fly test were uninjured.

Smith (31) in North Dakota found that certain varieties of spring wheat were more injured by grasshoppers than other wheats. Stage of maturity and amount of rust at time of grasshopper feeding appeared to influence the degree of damage.

Jacobson and Farstad (16), in a study of 41 varieties of wheat, found distinct varietal differences in the number of heads cut off by grasshoppers.

Strickland (33), working in Canada in 1931, found in cage tests that plants of Marquis and Reward suffered less injury than Garnet from the prairie grain wireworm. Seeds of Garnet, however, were less damaged than seeds of Marquis or Reward.

Tests by Harris, *et al* (14) in North Dakota show the "green grain bug" (*Chlorochroa uhleri* Stål) to be capable of reducing the yield and grade of grain and of seriously damaging the milling and baking qualities. The damage to 13 varieties of spring wheat ranged from 17% for Renown and 18% for Thatcher to 55% for Kubanka.

Wadley (35) found Mindum (durum) and Vernal emmer to be unfavorable hosts of the green bug.

In correspondence Atkins[5] reports that Marquillo×Oro selections showed relatively high resistance to the green bug at Denton, Tex., as compared with adjoining plats of other varieties. A leaf rust-resistant strain of Mediterranean produced some yield in a number of fields, whereas Tenmarq in adjoining fields was killed by the green bug.

Painter and Bryson (24) report that durum wheats were more heavily infested by the wheat strawworm than Vulgare wheats. Einkorn was not infested.

Painter, *et al.* (25) found a number of clear-cut cases of tolerance to the wheat jointworm in Marquillo winter hybrids. From observations of many varieties of wheat under conditions of severe jointworm infestation, the writer is of the opinion that no winter wheat is immune

[5]I. M. Atkins, U. S. Dept. Agr. Bur. Plant Ind., Sept. 5, 1942.

to infestation, but that hard, strong-stemmed strains generally show little or no breakage and support few galls. Weak-strawed varieties invariably are 100% infested and the straw breakage is severe.

In 1935, Jones (17) studied the reaction of 168 strains of wheat, principally winter varieties, to a heavy infestation of the chinch bug. A classification of strains according to injury, after rains had destroyed infestation, showed 20% of the strains to have suffered little or no injury while 80% were moderately to severely damaged.

That many of the insects mentioned above are of only sporadic occurrence and do less general damage than the hessian fly may account for lack of breeding work to develop strains of wheat resistant to them. From the reaction to attack by the chinch bug, grain bug, jointworm, and some other insects observed in selections of certain hybrids being developed for combined fly and disease resistance, it seems probable that some of these varieties may be resistant to other insects also.

Much groundwork is required in successful crossbreeding to synthesize new insect-resistant varieties. The plant, the insect, and plant-insect relationships must be studied in fullest detail. Environment, degree of maturity at time of feeding, oviposition, development of the insect, composition of the plant as affected by amount of light and soil moisture, and other factors may cause the plant either to escape infestation or to vary in its susceptibility to infestation. The presence of disease and the different biological strains of insects may also affect the reaction of the plant to insect attack. The effects of all these factors must be taken into account in the interpretation of the results obtained in any breeding program if erroneous conclusions are to be avoided.

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# INSECT RESISTANCE IN SORGHUM AND COTTON[1]

R. G. DAHMS[2]

## SORGHUMS

SINCE the main insect pest of sorghums in the United States is the chinch bug, *Blissus leucopterus* (Say), it is only natural that the major portion of the effort to produce sorghum varieties resistant to insect injury has been concerned with resistance to this insect. Under most conditions, crop plants exposed for the longest time to the attack of a specific insect would be expected to be most resistant to that insect. In distinct contrast to this expectation, however, is the relationship of sorghums to the chinch bug. Neither the chinch bug nor any closely related species is known to occur in Africa or Asia where the sorghums originated. When sorghum varieties were exposed to infestation by chinch bugs in the United States, however, they were found to differ greatly in their resistance to this insect.

Ball and Leidigh (2)[3] were among the first to report the susceptibility of milo to chinch bugs. Since that time many writers have confirmed the susceptibility of milo and called attention to the resistance of kafirs, Darso, and certain sorgos.

Hayes (22) reported that milo crosses exhibiting hybrid vigor were not injured by chinch bugs. Parker (39) and Parker and Painter (40) described the reaction of certain sorghum varieties and hybrids to the chinch bug at Manhattan, Kans., and showed that chinch bug resistance in sorghums is inherited.

The most complete and detailed information on resistance of sorghums to the chinch bug is the work by Snelling and his coworkers (48). They studied the chinch bug reaction of most of the important and standard varieties of sorghums and concluded that, in general, the milos are very susceptible, the feteritas susceptible, and the kafirs and sorgos rather resistant. Most of the sorgos tested by them were slightly more resistant than the kafirs, but others were susceptible. Results obtained by them suggest that resistance is dominant or partially dominant, although the continued manifestation of heterosis in the $F_2$ generation of the crosses studied may have increased the average resistance to the population. They obtained some evidence in a cross between Sharon kafir (resistant) and Dwarf Yellow milo (susceptible) indicating that one main factor governed chinch bug resistance in this cross. They concluded, however, that there was evidence that the inheritance of chinch bug resistance is more complex and is influenced not only by other genes directly affecting chinch bug reaction but by genetic factors controlling such plant characters

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[3]Figures in parenthesis refer to "Literature Cited", p. 713.

as earliness, vigor of early growth, character of sheath, and others. They also stated that the occurrence of several lines apparently homozygous for intermediate reaction to chinch bugs, and the fact that several hybrid selections were found that were more resistant than the resistant parent, indicated that chinch bug resistance in sorghums is not governed by a single factor.

Snelling and his coworkers also showed that natural selection is an important factor in chinch bug resistance in sorghums. Certain varieties that were apparently homozygous for agronomic characters but which had never been subjected to chinch bug injury were shown to be heterozygous for the genetic factors governing resistance or susceptibility when grown in the presence of chinch bugs. In such cases they were able to increase the resistance of some varieties of sorghums simply by growing them in the presence of chinch bugs and selecting seed from those plants that received the least injury.

Snelling and Dahms (47) and Snelling, *et al.* (48) presented data showing the advantage possessed by early planted sorghums when chinch bug infestation is severe. They reported that early planted sorghums and early maturing varieties were larger when the chinch bugs migrated into the fields and consequently showed the least injury and produced the highest yield.

Snelling, *et al.* (48) made some studies of the cause of chinch bug resistance in sorghums. An attempt to count chinch bugs on plants of Kansas Orange (resistant) and Dwarf Yellow milo (susceptible) growing under field conditions did not indicate preference for the more susceptible variety; but these authors also report that observations in years of light infestation at Manhattan, Kans., showed a high concentration of bugs on susceptible varieties. A count of the punctures (or stylet sheaths) in plants of Kansas Orange and Dwarf Yellow milo indicated that bugs fed about equally on the two varieties. However, approximately equal numbers of punctures were found on the leaf sheaths and blades of Kansas Orange sorgo plants, while on Dwarf Yellow milo there were more than three times as many punctures on the leaf sheaths as on the leaf blades. These authors also studied the relationship between many morphological characters and chinch bug resistance. They concluded that chinch bug resistance or susceptibility is not definitely determined by any one of the gross morphological characters studied.

Dahms and Martin (10) pointed out the difficulty in determining whether the high resistance of $F_1$ sorghum hybrids is genetic or merely a result of the rapid and heavy plant growth usually exhibited by sorghum hybrids. They determined the resistance of 11 $F_1$ sorghum hybrids by determining the number of eggs laid by chinch bugs when confined to the stems of the plants. In most of the crosses, resistance as measured by such counts was dominant to susceptibility. The extent of hybrid vigor as measured by height of plant, diameter of stalk, and number of tillers did not appear to be definitely associated with chinch bug resistance as measured by oviposition and longevity of the females.

The preference of chinch bugs for seedling sorghum varieties and the tolerance of several varieties to a uniform chinch bug attack was

studied by Dahms, Snelling, and Fenton (11). These authors also determined the effect of different sorghum varieties on the oviposition and longevity of the adult chinch bugs and the rate of development and mortality of chinch bug nymphs when confined to resistant and susceptible varieties. In a series of tests on the preference of the chinch bug to Dwarf Yellow milo (susceptible) and Atlas sorgo (resistant), 80% of the bugs were attracted to the susceptible variety. They also found that 10-inch plants of Atlas sorgo lived longer than plants of the same size of Dwarf Yellow milo under the same chinch bug infestation. Chinch bug females lived longer and laid many more eggs on the susceptible variety Dwarf Yellow milo than on any of the other varieties tested, and nymphs reared on Dwarf Yellow milo developed more rapidly and had lower mortality than those reared on Atlas sorgo.

Dahms and Fenton (9) found that the resistance of both resistant and susceptible varieties was consistently decreased by the addition of sodium nitrate to the soil, and in the majority of cases was increased by addition of superphosphate.

A discussion of the possible mechanism of chinch bug injury to sorghums was given by Painter (38). The object of the insect puncture on the plant is to reach the phloem tubes, and it is suggested that plant injury may come from stoppage of the tubes with a secretion. Tannins are also suggested as a possible factor in resistance.

Webster and Mitchell (57) studied the nitrogen fractions in field-grown Atlas sorgo and Dwarf Yellow milo plants and found that the milo plants were higher in nitrogen content than the Atlas plants. Most of the differences in soluble nitrogen content between the two varieties could be accounted for in the basic and alpha amino nitrogen fractions.

After more detailed chemical analyses of Atlas sorgo and Dwarf Yellow milo plants, Webster and Heller (58) reported the following differences: (a) Milo always contained some sucrose, and generally contained large amounts, whereas Atlas rarely contained any appreciable amounts; (b) the total nitrogen content of Atlas normally decreased with growth whereas milo percentages increased; (c) the chlorides values were usually higher in milo; (d) milo plants were generally found to be higher in phosphorus, potassium, and calcium. Analyses were also made on the two varieties and no significant differences were indicated in the following: (a) Solids content of the juice; (b) acidity measurements; (c) astringency values, including tannins; (d) conductivity; (e) catalase, oxidase, and peroxidase activity; and (f) hydrocyanic acid content.

No sorghum variety has been obtained that is immune to the chinch bug, but progress has been made in the development of resistant varieties by hybridization and selection. Types resembling feterita and milo have been developed that are much more resistant than the original varieties.

The resistance of sorghums to other insect pests has received some consideration. Hsu (25) reported on the resistance of 1,073 sorghum strains to the stem borers, *Pyrausta nubilalis* (Hbn.) and "*Diatraea diatraea*", at Peiping, China. His data indicated that the extent of

infestation differed among varieties. Under controlled conditions, sorgos as a group were more susceptible to these insects than the nonsaccharine varieties. He suggests that host selection of the "laying" moths is a possible cause for the varying degree of infestation in different varieties. White grain varieties showed less infestation by borers than varieties with other grain color. The reason for this relation is unknown, however, and he suggests that possibly some other characters associated with white grains may be important factors in borer resistance.

Riley, *et al.* (45, page 252), Helder (23), Dean and Kelly (12), Milliken (35), Hume (26), and Hume and Franzke (27) all called attention to the resistance of sorghums to grasshopper injury compared with that of corn. This fact was brought out by Brunson and Painter (5), who also reported that observations in the sorghum nursery showed slight but consistent differences in grasshopper injury to different varieties. In general, injury to the sorgos and the kafirs was less than to milo and to some of the newer varieties originating from hybrids involving milo.

The only mention in the literature in regard to resistance of sorghum to the corn leaf aphid, *Aphis maidis* Fitch, is by McColloch (34). He stated that all varieties studied were attacked by this insect, but that apparently there was a difference in injury of the different varieties.

All sorghum varieties appear to be susceptible to the sorghum midge, *Contarinia sorghicola* (Coq.), but quickly maturing varieties, such as feterita and milo, planted early, usually produce grain before the midge appears in sufficient numbers to do serious damage. Ball and Hastings (3) reported that Sumac sorgo seemed to be practically resistant, probably owing to the very short glumes; and Karper, *et al.* (31, page 44) stated that Shrock seemed to produce seed better under midge conditions than other varieties. Cowland (8) reported that in Sudan some varieties seemed to be more resistant than others. Walter (54), after testing the reaction of 43 varieties of sorghum to the midge, made the following statement: "So far no varietal resistance has been definitely shown and all varieties seem to be attacked to the same degree. Such differences as were observed at San Antonio appeared to be due to the greater uniformity in blooming in some varieties than in others or to the influence of varied growing conditions in different plots on the length of the blooming period."

The use of resistant varieties to lessen injury from insects that attack sorghums would appear to deserve more attention, because the control of insects on a crop of low value per acre precludes the use of insecticides. Furthermore, there is a possibility that the growing of resistant varieties would reduce the insect population; this certainly would appear to be true in growing chinch bug-resistant sorghums, since the resistant varieties have been shown to have an adverse effect on the chinch bug.

## COTTON

Several entomologists and agronomists in the United States and in other countries have studied cotton varieties in relation to various

cotton insects, and some progress has been made in controlling some of these insects by the use of resistant varieties or of varieties which, through earliness or some other characteristic habit of growth, escape serious infestation by one insect or another.

Soon after the boll weevil, *Anthonomus grandis* Boh., was discovered in Texas, the U. S. Dept. of Agriculture (55, page 687) sent an expedition to Guatemala to investigate the production of cotton there under boll weevil conditions. Members of this expedition found a dwarf upland variety of cotton that was much less injured by the weevil than nearby cottons. Protective morphological structures possessed by this type were the effective proliferation, small involucral bracts, and excessive hairiness over the plant surface. Seed of this cotton was brought back to the United States, but no boll weevil-resistant variety was ever developed from it.

In 1906 and 1907, G. N. Collins and C. B. Doyle made a trip into southern Mexico to investigate cotton culture under boll weevil conditions in that region. They brought back seed of an upland cotton which later became known as Acala. This variety and certain selections from it have been grown under conditions that demonstrated its resistance to drought and ability to produce crops in a short period in spite of boll weevil infestation.

Hinds (24) made extensive studies of proliferation as a factor in the control of the weevil. He showed that in some cases, when the boll weevil disturbed the cells of the square or boll, numerous elementary cells developed from the parts of the square or boll near the injury. These growths would often kill the larvae of the weevil by pressure. He found that the average mortality due to proliferation was 13.5% in squares and 6.3% in bolls. Proliferation in the varieties he studied ranged from 12.9% to 75.6%. There is no indication in the literature that the percentage of proliferation of recently developed cotton varieties has been investigated.

Early production of cotton and the use of early fruiting, rapidly maturing varieties have been recommended as a means of reducing boll weevil injury ever since the weevil was first introduced into the United States. On the basis of date of boll opening, many of the early maturing cottons are short-stapled varieties. Cook (7), however, pointed out that date of boll opening is a poor criterion for earliness, as far as its relation to boll weevil damage is concerned. He comments that, since the weevil does not injure the mature boll, the primary object is to produce many bolls in a short time, and it is not necessary to select short-stapled varieties to get a cotton of this type.

Lewis and McLendon (33) stated that the ideal cotton plant to be grown when the boll weevil is present should begin fruiting close to the ground early in the season, and have long fruiting branches at the base that continue to grow throughout the season. They also stated that, under boll weevil conditions, the more cotton that is produced on the lower half of the plant, the larger will be the yield per acre.

Isely (30) made studies to determine what part of the increase in yield of early maturing varieties was due to reduced boll weevil injury and what part to other factors. His results showed clearly that late-maturing varieties carry a much greater weevil hazard and also

that there is less to be gained by dusting on an early, rapidly maturing cotton. He pointed out that the natural fruiting period of a variety is greatly modified by the moisture supply, the soil type, and the soil management. Thus varieties that usually have a long fruiting period in the bottoms may have a short, almost determinate fruiting period in the light sandy uplands.

Fenton and Dunnam (17) made a study of boll weevil damage to cotton bolls and comparative cotton loss on two varieties of short-staple and one variety of long-staple cotton. They found a difference in the susceptibility of different varieties to boll damage by the weevil. Cotton loss of less than 10% resulted from weevil attack on the long-staple and one short-staple variety after the bolls were 20 days old. The other short-staple variety was more susceptible, the weevil being able to cause more than 10% damage up to 30 days after blooming.

In a study of cotton-boll growth in relation to boll weevil injury, Dunnam (14) found that as the cotton bolls grow older they are less susceptible to injury by the weevil and that the injury at given ages varies with the variety. He found no correlation between the numbers of feeding and of egg punctures and the percentage of cotton loss. Neither did he find any relation between the thickness of the hull and susceptibility to weevil damage in spite of the fact that the weevil lays fewer eggs on the thick-hulled varieties. He concluded that the determining factor is the hardness of bolls, because varieties with the hardest bolls, as determined by the number of grams pressure required to puncture them, showed also the lowest percentage of cotton loss.

Isely (29) made a study on the relation of leaf color and leaf size to boll weevil infestation in eight green-leafed varieties and four red-leafed varieties. He found that the boll weevil infestation in the red-leafed varieties was considerably less than in the green-leafed varieties. The average infestation in the green-leafed and red-leafed plots, respectively, on August 17 was 43.87 and 14.25; on August 24, 53.94 and 16.12, and on August 31, 58.62 and 32.25%. In this paper Isely reported that the boll weevil apparently makes little choice between small- and large-leafed varieties, provided the size and vigor of the plants are about the same.

An investigation of the varietal character of cotton in relation to attack by the boll weevil was reported by Strong (50, page 54). Of 44 varieties of cotton studied, those producing bolls with walls of medium thickness were less damaged by the weevil than those with either thick or thin boll walls. A negative correlation was found between boll-wall thickness and toughness of the carpel lining as measured by a resisto-meter.

Sea island cotton is known to be much more susceptible to the boll weevil than the upland varieties. The rind of the sea island cotton is thin and easily penetrated by the weevil, and the bolls remain subject to weevil injury during the entire maturation period. Moreover, the fruiting of sea island cotton is not sufficiently early or uniform and the period of boll development is too long to enable the plants to escape devastation by the weevil. Breeding work, according to Ware (55, page 690), has not been very effective in furnishing strains that

would provide any assurance of a crop under heavy infestation by the boll weevil. Recently it has been reported, however, that earlier strains of sea island cotton are now being developed which will escape injury by this insect to some extent. Some breeding work with extra-long-staple upland varieties has also been carried on to obtain suitable upland strains to replace sea island where the latter cannot be grown on account of weevil damage. Meade, an upland variety developed in Texas, has fiber that somewhat resembles that of sea island cotton. When this variety was grown in southeastern Georgia under severe boll weevil conditions, it yielded three to four times as much as sea island cotton. However, soon after this variety was developed it became contaminated and mixed with the fuzzy-seeded upland cottons. Breeding and selecting is now being done with this variety and with other varieties like Tidewater, Wilds, Ewings Long Staple, hybrids among these, and hybrids of these and sea island.

Perhaps the outstanding example of resistance by cotton to insects is its resistance to the cotton cicadellids, or leafhoppers, which include *Empoasca facialis* (Jac.), *E. devastans* Dist., *E. terrae-reginae* Paoli, and probably others. These insects sometimes seriously injure cotton in Africa, India, and Australia. At least one variety has been found that is completely immune to cicadellid attack, and some other varieties are very resistant. The resistance of cotton to these insects has been reported by Parnell (41, 42), Worrall (60, 61), Lal (32), Sloan (46), Moerdyk (36), and others. They all agree that the chief factor in resistance is the hairiness of leaves. Lal studied the resistance of seven varieties of cotton to cicadellids and found that the resistant varieties had short hairs and extreme hairiness. The most hairy American varieties, which also had the greatest average hair length, were not the most resistant. Some evidence obtained by Lal indicated that resistance to cicadellid attack may be due to some peculiarity of the veins that prevents oviposition. Parnell (41, 42) reported that the Cambodia variety introduced into South Africa from India was the only variety that showed complete immunity to *Empoasca facialis*. All newly imported American varieties were very highly susceptible. He states that all resistant plants were distinctly hairy but that all hairy plants were not necessarily resistant. Degree of hairiness and length of hairs are both concerned. Of several varieties tested by Parnell, one variety with comparatively sparse and very long hairs was highly resistant, two with high density and long hairs were very resistant, and two varieties with sparse hairs of moderate length were very susceptible. The most highly susceptible types of all had the fewest hairs. No extremely hairy types have yet been found with very short hairs.

Worrall (60) studied the resistance of American upland cotton to the cicadellid. He reported that in most fields individual plants could be found that were resistant and that these plants were thickly covered with hairs on leaf, stem, and bracts. Sloan (46) observed that cicadellid-resistant cottons imported experimentally from South Africa into Queensland remained resistant to the cicadellid but were inferior in quality. He found that resistant plants were typically hairy on the lower surface of the leaves, petioles, stems, and bracts.

Very little information is available on resistance of cotton to the bollworm, *Heliothis armigera* (Hbn.). Parnell (43) found that the adult moth was attracted particularly to the better developed plants and preferred the more fruitful varieties, so the best strains were likely to be most damaged. As a result, poorly developed and lightly fruiting types sometimes yielded more than good, heavily fruiting types nearby. Pomeroy (44) stated that bollworms did not damage American cotton so much as native Nigeria cotton because the developmental period of the former was shorter.

Ballou (4), Chapman (6), and Storey (49) all agree that early ripening varieties of cotton are of considerable importance in minimizing attacks by the pink bollworm, *Pectinophora gossypiella* (Saund.). Chapman (6) tested a number of varieties but found all of them to be 100% infested. However, there did appear to be some indication that the grade was not lowered so much in the varieties with high lint percentages or high lint index as in the varieties with low lint percentages or low lint index. The results of spacing tests indicated that close spacing hastened maturity and tended to reduce the late seasonal pink bollworm damage. Audant and Occenad (1) found native Haitian perennial cotton resistant to attack by the pink bollworm. They stated that when the native cotton was grown in experimental plats beside many other kinds of cotton its resistance to pink bollworm attack was very marked. When this cotton was grown commercially in absence of other varieties, the pink bollworm practically ceased to exist.

Wolcott (59) found many pink bollworms in Haiti in 1924 but had difficulty in finding native cotton infested, although all other varieties were highly infested. It is not known whether Haiti native cotton will retain its resistance outside the West Indies.

Pomeroy (44) noted that cotton stainers, *Dysdercus* spp., preferred American cottons over indigenous Nigerian cotton. Parnell (43) found that injury by stainers was greater on cotton with a bushy, leafy growth. He stated that this might have been wholly or partly due to its greater attractiveness and consequent heavier puncturing of the bolls, increased infection by the fungus involved, or difference in the physiological condition of the bolls and their reaction to infection. Strong (51, page 70) reported that 31.5% of the bolls of short-staple cotton in Arizona were punctured by pentatomids and capsids as compared with 14.6% of bolls of long-staple varieties. Mumford (37), in a preliminary study of the effect of climate and soil conditions on the resistance of cotton to the cotton stainers, found that the disturbance of the water balance in the cotton plant increased its susceptibility to cotton stainers. He suggested that this condition rendered the sap more attractive by altering the concentration or constitution of the carbohydrates in it. He also suggested that the chemical composition of the soil is important in affecting the susceptibility of the cotton plant to insect attack.

In recent years considerable work has been done in Texas and more recently in Oklahoma on the resistance of cotton to the cotton flea hopper, *Psallus seriatus* (Reut.). Thomas, *et al.* (53) tested 20 varieties of cotton and found considerable variation in the ability of different

varieties to retain squares in the presence of a slight flea hopper infestation. Certain varieties appeared to possess a high degree of resistance, whereas other varieties grown under the same conditions lost a large proportion of minute squares. Gaines, *et al.* (18) found that early and late-maturing varieties had higher flea hopper infestation than intermediate varieties. Strong (52, page 80) reported that the seasonal flea hopper infestation of four varieties of cotton with different plant and growth characteristics was more than twice as high in the most susceptible as in the most resistant variety. There was also a marked varietal difference in the injury by flea hoppers in the untreated cotton and some indication that insecticides were more effective against the flea hopper on some varieties than on others.

Dunlavy, *et al.* (13) suggested that the Acala 8 strains seemed to be more susceptible to flea-hopper attack than other types. They also found that the size of the boll of some varieties was reduced. Acala 8 strains and many Mebane strains were adversely affected in this manner, but the Stoneville and Lankart strains were not.

The effect of time of chopping and number of stalks per hill on infestation of thrips, *Frankliniella* spp. and *Sericothrips variabilis* (Beach), was studied by Dunnam and Clark (15) on 40 varieties of cotton. They reported varietial variation of 13.8 to 5.5, 40.34 to 5.0, and 38.56 to 11.24% of terminal buds destroyed under three conditions of growth, but they did not state whether the same varieties were low or high in each condition. They concluded that no difference in varietal infestation was observed, but suggested that the type of terminal bud in different varieties might have had some effect on the damage. Nevertheless, there were six varieties which produced more seed cotton on the injured plants than on normal plants, indicating a difference in the ability to produce cotton in spite of thrips injury. Watts (56) noted that late cotton regularly suffered more thrips injury than did that planted early.

Harland (20) reported that the nigra, or black, scale, *Saissetia nigra* (Nietn.), was a serious pest of sea island cotton when it was first introduced in the West Indies. However, two types of Seredo cottons were quite immune to this scale, the immunity being inherited and in breeding experiments behaving as a partial dominant.

The immunity and inheritance of immunity of cotton to the cotton blister mite *Eriophyes gossypii* Banks, which sometimes is a serious pest to cotton in the West Indies, has been studied by Harland (19, 21). West Indies cottons are in two groups in regard to this pest; thus (a) they may be immune or (b) they may be attacked although still fairly resistant. Sea island cotton is very susceptible. In general it may be said that the nearer an indigenous cotton approaches the sea island variety in morphological characters, the more susceptible it may become. In a study of budded cotton, Harland found that the only scion which remained immune was one that was budded on the susceptible sea island stock. When a susceptible scion was budded on immune stock, the resistance was apparently increased; but when the stock was fairly resistant and the scion susceptible or *vice versa*, the susceptibility or resistance of the scion remained unchanged. Harland studied the $F_1$, $F_2$, and $F_3$ generations of a cross between immune and

susceptible types. The $F_1$ was intermediate though inclined toward the susceptible parent. In the $F_2$ generation, segregation occurred into immune and nonimmune; and in $F_3$, immune bred true while nonimmune segregated into immune and nonimmune. Although these results would seem to indicate that immunity to the cotton blister mite is definitely an inherited character, Harland (21) says, "* * * it is the opinion of the present writer that immunity to this mite is not yet shown to be inherited as a simple Mendelian factor."

The effect of pilosity of cotton on the population of the cotton aphid, *Aphis gossypii* Glov., was studied by Dunnam and Clark (16). The aphid population found on undusted cotton was in direct proportion to the number of hairs per square millimeter on the lower leaf surface where this insect was breeding. In one test the pilose cotton, as compared with the almost glabrous cotton, had 5.8 times the number of live aphids. No varieties have been found that are immune.

Husain, *et al.* (28) found that the cotton whitefly, *Bemisia gossypiperda* Misra and Lamba, fed and laid more eggs on cotton with tender leaves. It infested indigenous Indian varieties more severely early in the season and American types in July and August. They found that this was primarily due to the pH of the cell sap. The relative incidence of infestation corresponded with the trend of the pH curve, indicating partiality toward higher pH values.

As shown by the examples mentioned, there appear to be definite possibilities in reducing insect damage to cotton by the use of varieties that possess actual resistance to insects or certain habits of growth that enable them to escape insect infestation. The use of such varieties, however, probably will never entirely replace insecticides as a means of controlling the major cotton insects. Nevertheless, the fact that several of these can be controlled by the application of insecticides does not necessarily reduce the value of resistant varieties, because there are always some farmers who are not prepared to apply insecticides. There is also an advantage in the saving of labor, money, and material through the development and use of resistant varieties. Resistant varieties would be particularly valuable against such insects as the pink bollworm, because no effective method of insecticidal control is yet known. Even after resistant varieties are developed, further breeding work will be necessary because of the continuous danger of their becoming contaminated and mixed with other varieties, both by cross pollination in the field and by mixture of seed at the gin.

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# INSECT RESISTANCE IN FORAGE PLANTS[1]

RALPH A. BLANCHARD[2]

BECAUSE of the relatively low per acre value of forage crops, cultural methods and the use of resistant strains appear to offer the best means of controlling insects that attack forage plants. The definition of insect resistance that seems to be generally accepted is given by Snelling (30)[3] as "those characteristics which enable a plant to avoid, tolerate or recover from the attacks of insects under conditions that would cause greater injury to other plants of the same species."

References pertaining to this subject were obtained from the bibliographies by Snelling (30) and Platt and Farstad (23). Further information on the most recent developments in this field was obtained by correspondence from a number of the men working on these problems.

Studies on insect resistance in forage plants have been limited to a very few insect species, some of which affect more than one type of forage plant.

## POTATO LEAFHOPPER

The potato leafhopper, *Empoasca fabae* (Harr.), causes widespread damage, especially in the eastern half of the United States, to a wide variety of plants, including apple, potato, clovers, alfalfa, beans, and peanuts. Of all the forage plants, alfalfa appears to be the most seriously damaged by this insect. Jones and Granovsky (19) were perhaps the first workers to demonstrate experimentally that this leafhopper caused the disease-like condition known as "alfalfa yellows." The attack of the leafhoppers causes the leaves to turn yellow, then bronze or purple, and die prematurely. New leaves formed after the attack are much smaller than normal, the internodes of the stems become much shortened, and the whole plant may become stunted. On the older stands the second and third crops are the most heavily infested and the "yellows" may result in increased winterkilling, although tests by Jewett (14) in Kentucky did not show this to be the case there. New stands may be killed outright. Records indicate a measurable reduction in hay yield of from 14 to 50%. Poos and Johnson (26) have shown that the severity of injury is directly correlated with the number of leafhoppers present.

Smith and Poos (28) and Smith (29) attribute the damage to a disease-like injury resulting from the deposition in the vascular tissue of a highly insoluble sheath that probably interferes with the normal

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[2]Entomologist.

[3]Numbers in parenthesis refer to "Literature Cited", p. 723. In addition, the following men wrote letters to the author telling of the status of work at their several institutions on resistance of forage crops to insect attack; T. R. Chamberlain, L. G. Jones, C. J. Sorenson, and V. L. Wildermuth.

translocation of plant materials. Johnson (17) concludes that the injury is not due to any specific agent but to an accumulation of the carboyhydrate products of photosynthesis where a plugging of the phloem tissues is caused by the leafhoppers.

Apparently none of the commonly grown commercial types of alfalfa are resistant to the potato leafhopper. Considerable variation, however, occurs in the amount of damage within alfalfa strains. Poos (unpublished correspondence) mentioned the fact that one coarse-stemmed selection studied at Arlington Farm, Va., stood up well under heavy leafhopper populations, and that some of the pasture types are fairly resistant. As far as can be determined, no attempt has been made to utilize resistant types for the purpose of breeding resistance into the commercially grown alfalfa varieties.

The potato leafhopper affects susceptible varieties of red clover in much the same way as it does alfalfa. The relationship between the potato leafhopper and the yellowing and dwarfing of red clover was suspected by a number of workers but was first demonstrated by Hollowell, Monteith, and Flint (12). The pubescent types of American clovers are not seriously affected, whereas the more glabrous English, French, and Italian varieties are severely damaged. Pieters (25) attributes the resistance shown in the American types to natural selection during the 200 years or more that these clovers have been cultivated in America. He records the supposition that the resistant hairy types set more seed than the susceptible smoother types, thereby gradually replacing them. Poos and Smith (27) found that, in general, the rough-hairy pubescent varieties within a species usually were less damaged than the nonpubescent or appressed-pubescent varieties. In certain varieties, however, the rough-hairy pubescence was not the prime reason for their greater resistance. In later tests Poos and Johnson (26) found that when leafhoppers were allowed a choice, 74.6% of the total nymphs hatched on glabrous Italian clovers and only 25.4% on a native rough-hairy Ohio strain. Jewett (14) suggests the possibility that characters other than pubescence might also be responsible for resistance. He (15.16) found a positive correlation between the comparative resistance of five varieties of red clover and the resistance of their leaves to puncturing.

From their studies on the effects of the potato leafhopper on soybeans, Hollowell and Johnson (13, 18) concluded that freedom from injury by this insect is correlated with the occurrence of rough-hairy pubescence. Studies of the $F_3$, $F_4$, and $F_5$ generations from a cross between the rough-hairy Illini variety and a dominant glabrous soybean were made. In all three generations the homozygous glabrous and heterozygous progenies were all heavily damaged and stunted. The homozygous rough-hairy lines were entirely free from injury and grew vigorously. Glabrous and appressed-hairy soybean introductions from the Orient were also studied. The glabrous types were severely damaged while the appressed-hairy types showed no marked injury, although some yellowing of the leaves occurred. Some of the glabrous strains included individual rough-hairy plants that were free from leafhopper injury. It would therefore appear that any new commercial varieties produced for growing in the eastern half of the

United States will need to be of the rough-hairy or appressed-hairy types if leafhopper damage is to be avoided.

## PEA APHID

The pea aphid, *Macrosiphum pisi* (Kalt.), causes widespread damage to a number of forage plants, including peas, alfalfa, red clover, and vetch. In the case of alfalfa certain cultural methods of control have been partly successful, but the development of resistant strains seems to offer the most possibilities.

Blanchard and Dudley (7) observed alfalfa plants that escaped damage in badly damaged fields in California and in the course of greenhouse tests in Wisconsin. The tests reported by Dudley in 1934 and tests of $F_3$ lines made subsequently by R. A. Blanchard and L. G. Jones showed some strains to be practically immune to the pea aphid. More recent unpublished work by L. G. Jones and F. N. Briggs has shown that aphid resistance is an inheritable character and that modern breeding methods can be used in the development of aphid-resistant as well as agronomically desirable lines.

Painter and Granfield (24) observed wide variations in the amount of damage in, and the number of aphids swept from, different varieties of alfalfa in test plots in Kansas. The variety Ladak had only 10% of injured plants as compared with 70% for Turkestan No. 19316. Eichmann and Webster (10) confirmed the resistance of Ladak in Washington but doubted its suitability for forage in that state.

In 1936, Albrecht and Chamberlain (3), in greenhouse tests of seedling $F_2$ hybrid progenies of the resistant strains isolated in Wisconsin, obtained results similar to those obtained by Dudley. In a repetition of the tests in 1937, using year-old plants, little difference in reaction between the progenies of resistant and susceptible parents was observed. Poor illumination and occasional subjection of the plants to low temperatures was mentioned by the authors. They conclude, however, that resistance in these plants was not a stable character and that until the relation of environment to the expression of resistance to aphids is better known, it is impractical to determine the precise manner of inheritance of the resistant character. Blanchard (unpublished notes) likewise observed that poor illumination resulted in modification of resistance.

Dahms and Painter (9) tested individual plants selected on the basis of having shown definite resistance or susceptibility in field plots. They also selfed these selections and tested the progeny. A wide variation was noted in the rates of aphid reproduction and percentages of aphids dying on the parent plants. One resistant selection (Turkestan F. C. 19316) allowed an average increase of less than 1 aphid per parent and a mortality rate of over 80% under temperatures of 78°, 61°, and 57° F, respectively. At 61° an average of 7.4 aphids per female was produced on 16 other resistant plants and 46.2% were dead at the end of 10 days, as compared with 27.3 aphids per female and 2.2% mortality on 10 susceptible plants. At 44° there was an increase of 8.9 aphids per female and a mortality of 1.0% on the resistant plants as compared with a 9.9 aphid increase and only 0.1% mortality on the susceptible plants. On the progeny of 12 selfed resis-

tant selections there was an average increase of 0.9 aphid per female in 10 days as compared with an average of 5 per parent on the progeny of selfed susceptible selections. Aphids confined to the flowering branches in these tests reproduced much faster than those confined to vegetative branches of the same plant.

No single plant character has been definitely associated with resistance of alfalfa to the pea aphid. It appeared at one time that the resistant lines from the California material were a deeper green than susceptible lines. As mentioned earlier, resistant lines which lost their green color because of poor illimination also tended to lose their resistance. Aphids feeding on the immune or highly resistant lines gradually became shrunken and dark green and were restless upon the plants.

Unpublished studies by W. T. Emery at Manhattan, Kans., indicate that pea aphid resistance in alfalfa may be correlated in part at least with the proportion of schlerenchymatous tissue, and of lignin in the walls of the parenchyma of the rays, in the growing shoots.

Albrecht (2) observed differences among both species and varieties of vetch in resistance to the pea aphid. More than 20 species and varieties were observed during severe infestations in 1937 and moderate infestations in 1938 and 1939. Based on foliage injury 10 strains were resistant, 8 were susceptible, and 8 highly susceptible. Of four selections from *Vicia sativa* No. 34947, one was severely injured, two slightly injured, and one was unharmed. Of 40 hairy varieties of *V. villosa* included in a progeny test, 10 were injured by the pea aphid. Field observations and cage tests showed that the green pods and inflorescences of both resistant and susceptible varieties could be severely damaged by aphids. This is given as one of the reasons for small seed production in the vetches studied.

## CHINCH BUG

An interesting study of the reaction of a hundred species of grasses to attack by the chinch bug, *Blissus leucopterus* (Say), was made by Hayes and Johnston (11) in a special grass garden at the Kansas State Agricultural College at Manhattan. The grasses in this garden suffered from a severe infestation of bugs migrating from nearby wheat plots. They state, ". . . those grasses having harsh tissues seem, in most cases, to be especially resistant, if they are native grasses. For example, such a plant as *Andropogon scoparious* has harsh tissues and is a native perennial. . . . In the majority of instances of those grasses termed 'harsh' in which chinch-bug injury was severe and recovery poor, the species were introduced ones." Among the plants with tender tissues they observed only one species (a native species) which showed but slight damage. A few species showed only moderate injury. The majority of tender grasses were either severely injured or completely killed. They noted one instance, in the case of *Hystrix hystrix*, in which the age of the grass seemed to make no marked difference in the ability of the plant to withstand injury. Bunch types were alike slightly injured or killed, and the same can be said of the turf, tufted, and dispersed types. They noted that several

species had matured and produced seed before the migration of the chinch bugs from the wheat to the grasses.

## JAPANESE BEETLE

Studies of differential injury to soybean varieties by the Japanese beetle, *Popillia japonica* (Newm.), are summarized in several unpublished reports of studies carried out by workers of the U. S. Dept. of Agriculture and of the New Jersey Agricultural Experiment Station. Keim (20) reports on 92 varieties and strains. He states that varietal differences in damage by the Japanese beetle do occur. Varieties of soybeans with dark-green leaves appeared to be less relished by the beetles than those with lighter leaves. He doubts whether color alone is responsible for this reaction, and it is his opinion that there are good possibilities that resistant commercial varieties can be secured through selection and breeding. According to Keim, similar work by I. M. Hawley conducted independently on the same plots resulted in almost identical conclusions.

T. N. Dobbins tested five soybean varieties in New Jersey in 1940, and J. L. King tested the same varieties in 1941 (unpublished reports to the Bureau of Entomology and Plant Quarantine). Although none of the varieties tested were immune to attack, there was a significant difference between varieties in amount of damage to the foliage. The differences in weight between beans from damaged plots and those from undamaged plots were not significant, however, when differences in potential yield between varieties were taken into account. These results indicated that in neither of the two years was the injury caused by the beetle to the foliage a significant factor in reducing either the number of pods or the weight of beans produced. In personal conversation, W. P. Flint mentioned that in test plots conducted in New Jersey by J. L. King in 1942, the amount of foliage destroyed ranged from 15% for resistant varieties to over 50% for the more susceptible ones.

## CLOVER SEED MIDGE

Metcalfe (22) reports white clovers as being immune to the clover seed midge, *Dasyneura leguminicola* (Lintn.), under insectary conditions and in field plots. She found a variation in percentage of damaged heads and the number of larvae per head between several varieties of red clovers but thought that this variation was due to time of flowering rather than to any resistant character in the plants.

## COWPEA CURCULIO

Tests of garden variety cowpeas for differential damage by the cowpea curculio, *Chalcodermus aeneus* Boh., are reported by Arant (4) and Bissell (5, 6). Arant found considerable variation between varieties in the number of peas damaged by this insect but was of the opinion that the resistance in the varieties tested was not of high enough order to provide control where the varieties are grown alone. In later tests Bissell also found considerable difference between varieties in the percentage of damaged peas. Puncture tests showed a

correlation between low degree of curculio injury and both toughness of pod and pea and smallness of seeds. Bissell considers time of bearing of more influence than variety upon damage by the curculio, the later plantings tending to be the least damaged. La Conch, one of the varieties reported by both Arant and Bissell as being resistant to the pea weevil, was also reported by Arant to be resistant to nematodes and adverse weather.

## LYGUS, spp

Aamodt and Carlson (1) state that alfalfa varieties differ considerably in their ability to flower in spite of *Lygus* bug injury. Bugs were present in all varieties in about equal numbers, and the difference in flowering apparently resulted from the differences in ability of the varieties to recover from damage. Grimm alfalfa showed the most resistance in their tests, and Turkestan, Cossack, and Ohio Common were the most susceptible. Certain strains of Grimm were reported as being more resistant than the average of that variety.

## FRIT FLY

Cunliffe (8) studied at least 70 varieties of oats from various parts of the world for resistance to the frit fly, *Oscinella frit* (L.). This fly causes widespread damage in Europe to oats as well as wheat and many other species of the grass family. Summer, a Swedish variety of oat, was the most resistant. Cunliffe crossed this variety onto the varieties of agricultural importance in England and concluded from a study of these crosses that resistance to this insect was a definite, inheritable character. Selection for 8 to 10 generations reduced the character to a considerable degree of purity, although the resistance was not of a high order. He suggests that reduced damage in the resistant varieties may be due to increase in crude fiber or deposition of silica.

## GENERAL CONSIDERATIONS

Several authors have called attention to the possibility of reducing injury by a particular insect to more than one crop through the development of resistant strains of crops that serve as alternate hosts. Dudley, Eichmann, and Webster (10), and others have mentioned this possibility with regard to the pea aphid. Since alfalfa and the clovers serve as primary hosts from which this aphid migrates to peas in potentially injurious numbers, it might be possible to reduce damage to peas through the development of highly resistant varieties of alfalfa and clover. This would, of course, necessitate the general use of these varieties in the pea-growing areas. The same principle could perhaps be applied to the control of the potato leafhopper or any other insect having several host plants. Reduction in the size of insect populations through the development of resistant strains might also conceivably reduce the chances of transferring insect-borne diseases from plant to plant within plant types as well as between plant types.

Another consideration is the fact that insect resistance is sometimes variable in nature. Variability in resistance to the pea aphid of the

same alfalfa selections under different environmental conditions has already been mentioned, and other similar reactions are noted in the literature. For instance, Lees (21) gives 14 cases in which susceptibility to insect attack may vary with conditions under which the plant is growing. This fact should not deter workers in their efforts to develop resistant plant strains, but it should make them more cautious in accepting strains as being resistant. It should also make apparent the necessity of understanding the conditions favorable to the insect-plant relationship and of attempting to provide these conditions in conducting tests.

The fact that one part of a plant is resistant to an insect is no assurance that another part of the same plant is resistant also. Attention has already been called to the susceptibility to the pea aphid of the floral and seed-bearing portions of alfalfa and vetch plants, the vegetative parts of which were resistant. These are examples of what appears to be a fairly general condition.

## DISCUSSION

From a survey of the literature it appears that there is more evidence of resistance in forage crops to sucking insects such as the pea aphid and potato leafhopper than to the chewing insects.

Very few cases of the development of insect-resistant commercial varieties of forage plants were found in the course of this review. Strains highly resistant to the pea aphid, the potato leafhopper, and certain other insects are reported by careful observers. That there is a pressing need for the development of forage crops resistant to these insects is a matter of general knowledge. Why, then, has not greater progress been made along this line?

Several reasons may be advanced in answer to this question. In the first place, the concept of insect resistance in plants, while it goes back at least 150 years, has not received wide attention until in comparatively recent times. In the second place, the fact has only recently been recognized that insect resistance, when it can be found, is transmissible like other plant characters, and can be included in a general breeding program. In the third place, the attainment of the objectives of such programs requires a considerable period of time.

Although resistance to some insects may be correlated with an easily observable plant character, that is by no means always the case. It would therefore appear that rapid progress in developing resistance in forage crops to most insects can be made only by subjecting crosses involving resistant and susceptible strains to severe insect infestations. Since severe insect damage does not always occur year after year in breeding plots, methods of artificially subjecting breeding material to severe insect tests would no doubt result in more rapid progress. The entomologist could perhaps be of greater assistance in this regard if ways and means were brought about of integrating his knowledge and resources into the breeding programs. One need only drive across certain sections of the country east of the Mississippi to observe the need for strains of alfalfa, beans, and other legumes resistant to the potato leafhopper. The same may be said for other

insects in other parts of the United States. A closer cooperation between the agronomist, plant breeder, and entomologist might hasten the alleviation of this condition.

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# INSECT RESISTANCE OF PLANTS IN RELATION TO INSECT PHYSIOLOGY AND HABITS[1]

REGINALD H. PAINTER[2]

INSECT injury to plants results principally from the feeding of insects and studies of insect resistance in plants, particularly the causes of resistance, must primarily be concerned with how insects find and utilize food. The planning and execution of experiments dealing with resistance requires a knowledge of the habits and life history of the insect concerned. Both these fields of work involve insect physiology which is in many respects a new subject. The first comprehensive book on the subject was published by Wigglesworth (16)[3] in 1939.

The physiology of the insect cell is similar to the mammalian, but the physiology of organs and organ systems may be vastly different. There are wide physiological differences among the thousands of insect species, and so far only a few kinds have been studied extensively. Insect habits are better known than insect physiology, but there has been too great a tendency to interpret them in terms of what a man would do under the same circumstances. Such interpretations may or may not be correct.

## THE LOCATION OF PLANTS FOR FOOD OR OVIPOSITION

Food plants are located by insects through their various sensory organs and in this way they show a preference for certain plants. As a whole the senses of an insect appear to be less well developed than they are in man. But certain senses may be far more acute than in any mammal. Generally, senses and reactions of an individual insect species vary within narrow limits unless changed by mutation. Behavior in insects can rarely be modified by experience. Three or four senses are concerned in finding food. These are sight, the chemical senses of smell and taste, and touch.

The compound eyes of insects are very different from the mammalian eye and the structure is well known (14). In range of color vision many insects "see" ultraviolet light and are blind to red; some can distinguish between different wave lengths, but what they see may not be the same as the colors we see. Butterflies and showy flowers differ in their ability to reflect ultraviolet rays, but whether crop varieties differ in this regard is apparently unrecorded. Leaf-feeding insects in general are attracted to the color green, but the reverse has been noted in some cases. Red-leafed cotton has been reported (5) to be more resistant to the boll weevil than at least some

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[3]Figures in parenthesis refer to "Literature Cited", p. 732.

of the green-leafed varieties. Celery varieties with green leaves and stems have been observed (7) to be more resistant to the tarnished plant bug than varieties with yellow color. The yellow-green varieties of peas are more resistant to the pea aphid than the blue green varieties (11). In some or all of these the relationship may be with some physiological character of the plant associated with color.

The finding of food plants by insects is usually associated with the chemical senses, taste and smell, in which some volatile constituents of the plant are involved. Organs for the reception of odors are known to occur on various parts of the insect body, but are most common on the antennae where they may act as "direction finders" in contrast to the single location of the olfactory organ of mammals.

The reaction to odors does not include a wide variety in any individual species of insect, but in the case of those substances to which the sense organs are attuned the perception may be remarkably acute. Often single substances or groups of related ones are concerned. The Japanese beetle responds to geraniol, a substance found in geraniums and other plants on which the Japanese beetle feeds, and to related substances present in favored food plants. The cabbage butterfly is attracted to mustard oil found in its favored food plants among the Brassicaceae.

Plant breeders have produced cabbage and marigolds without their distinctive odor, thus indicating the possibilities of the production of plant varieties unattractive to insects. The preference of corn ear worm for oviposition on silks of sweet corn rather than field corn probably is an olfactory response.

There is some evidence that insects, such as some grasshoppers, distinguish food plants through the sense of taste. There is clear evidence that some insects may react to concentrations of sugar or other chemicals that are too low for human perception. Some organs of taste may be located about the insect mouth, but they have also been demonstrated to be present on the tarsi of the front feet.

Plants for food or oviposition are sometimes selected by insects largely through a sense of touch. In the extensive feeding and starvation tests made before cactus insects were introduced for the control of prickly pear in Australia, it was found that physical similarity was most often the factor governing the feeding of an insect on a species of plant new to it. Botanical relationships and chemical likenesses were of less importance (2). *Euaresta aequalis*, a fly breeding in cockle bur seeds, will attempt oviposition in an imitation bur but does not appear to be attracted by the, to us, obvious cockle bur odor, although this insect is rarely found far from its food plant. The relation of smooth and pubescent plant varieties to insect population has often been observed in resistance studies. In some cases, as cotton, red clover, and soybeans, at least, the effect of the pubescence comes through oviposition reactions rather than through food relationships.

The food-finding and egg-laying impulses in insects are typically chains of stimuli and reflexes which are conditioned not only by the internal physiology of the individual but also by external conditions of moisture, temperature, sunlight, etc., as well as food. Breaks in

this chain at any point may result in lower oviposition and may or may not be related to resistance.

The egg-laying apparatus of an insect varies from relatively simple tubes to complex structures used for inserting eggs into woody stems. Sense organs of various kinds, especially those concerned with touch and the chemical senses, are found on these structures. Such sense organs are concerned in the final actions of an insect toward the food plant for its larva.

## FOODS AND FEEDING OF INSECTS

When insects feed on resistant plants, there frequently follows various adverse effects on the insect fecundity and life history. These effects, called *antibiosis* (8, 9), apparently arise primarily from some interference with feeding or the lack of necessary food substances.

The essential problem among the plant-feeding insects is to get through the cell wall of the plant so that the contents may be digested. Insects solve this problem by the mechanical breaking up, by piercing of the cells, and by the action of enzymes through the cell wall. Enzymes capable of digesting cellulose have rarely, if ever, been found in insects feeding on plants.

The plant cells of particles of leaves, taken in by some insects with chewing mouth parts, appear to pass unchanged through the digestive system unless the cells are broken open. In other insects the cell contents appear to be extracted through the unbroken cell wall.

The food requirements of insects for growth and reproduction differ greatly among different species, but include, in addition to carbohydrates and proteins, certain elements, especially phosphorus and potassium and certain of the vitamins or vitamin-like substances. The absence or inaccessibility of any of these substances may be related to resistance.

Insects feeding on plants have mouth parts of either the chewing or the piercing-sucking types. The mandibles of the chewing insects are of a great variety of patterns and are sometimes adapted to special uses correlated with the plant structure to be attacked. Some caterpillars feed at the edge of a leaf, others normally on the surface; some use only the upper surface of the leaf, others only the lower. Connected with the mandibles of these insects is a large muscle attached broadly to the exoskeleton making possible considerable pressure at the cutting edge of the jaw. The power of such muscles is shown by the ease with which some insects tunnel through the hardest wood. Hardness of plant tissue has frequently been cited as a "cause" of resistance to various insects. Later research has sometimes shown that physiological relationships were of greater importance.

A consideration of insect structures and abilities leads one to question whether differences in hardness of tissue of the order of those occurring between varieties of a plant species is sufficient to explain many of the cases of resistance. For instance, during the grasshopper outbreaks of 1934 the grasshoppers near Manhattan ate much of the corn, chewed the bark off certain trees, and the labels off the stakes in the experimental sorghum nurseries, but only nibbled at the

sorghum leaves. Certainly a difference in hardness of tissue did not explain these choices and still less would such an explanation be probable in the case of differences found in amount of injury among different corn hybrids and varieties.

Differential toughness of pericarp has been cited as one cause for differences in extent of injury by corn ear worm to young corn kernels. In Kansas later generations of this insect tunnel through the hardened kernels and here also differential injury is shown by various hybrids. Those with softer, starchy kernels and also the hard flinty types occur both among hybrids with low and with high degree of injury by corn ear worm. Evidently, hardness of kernel is not a deciding factor in late injury by corn ear worm. It is still less likely to be a factor when the kernels are in the milk or dough stage.

Among the insects with piercing and sucking mouthparts, the mandibles and maxillae are formed into four needle-like stylets held within a jointed beak. The inner surfaces of the maxillae are grooved and when pressed together form two canals connected with muscular pumps in the head. Through one of these channels salivary fluid is forced into the plant; through the other plant fluids, which sometimes may be partially digested, are drawn back into the insect. These stylets are inserted into the plant by pushing first one and then the other forward while the base is held within the beak. Among some of the Hemiptera, such as the chinch bug, the stylets are thrust *through* the cells; among many of the other insects, including a majority of the aphids, the setal path is *between* the cells. Some species of insects employ both methods. Around the stylets within the plant there is formed a stylet sheath apparently coming mostly from the insect salivary glands. The punctures of these insects usually reach the phloem tissue, although in other species of insects, even some species belonging to the same genus (*Empoasca*), the required food comes from mesophyll tissue only. In the case of the sugar beet leaf hopper (3), the stylets are apparently guided to the phloem tissue by a hydrogen-ion gradient which tends to be more acid near the epidermis and more alkaline near the phloem.

Again in this connection the statement sometimes made that hardness of tissue is often a cause of resistance to sucking insects is open to question. Some of these insects normally feed on or send their stylets through or between cells of branches of trees where lignification is heavier than in most crop plants. The mechanism of piercing of these species of insects is not known to differ from related species feeding in softer tissue. It appears doubtful, for instance, if differences in thickness of epidermis to be found between the leaves of two varieties of a crop plant would be enough to encourage an aphid to feed on one and prevent it from feeding on the other. Differences in plant structure may be found, however, to be genetically linked with resistance and hence prove to be useful marks in searching for resistance.

The effects of the feeding of chewing insects is usually only too apparent, but the effects of the feeding of sucking insects may not be so easily measured. Sometimes little damage is done and large numbers of insects must be present before damage by aphids, for example,

can be measured. A part, often the principal cause of injury, is in clogging of conducting vessels of the plant by stylet sheath material. Some insects, notably the tarnished plant bug and its relatives, inject toxic fluid into the plant, resulting in considerable breakdown of cells and swelling or holes, especially where the injury takes place in a bud. It should also be remembered that some of these sucking insects are first-class transmitters of plant disease and that it may be possible in some cases to confuse resistance to insects with resistance to a plant disease carried by the insect.

The thrips (Thysanoptera) contain another group of plant feeders with sucking mouthparts that differ in many details from the aphids and other true bugs. In these minute insects the lower part of the head is drawn out into a cone containing three piercing stylets. A hole is made by the mandible through a single cell of the epidermis of the plant. Only a few cells near the point of puncture of the epidermis can be reached by the stylets and from these cells the plant fluids are drawn up by the insect. There is no clear evidence of any injection of salivary fluid. Considering the anatomical evidence, it appears possible that in this case a differential thickness of the wall of epidermal cells may be of importance in resistance. Cases where this appeared to be true have been reported (6) in onions.

## DIFFERENCE BETWEEN SPECIES AND WITHIN SPECIES OF INSECTS

Each species of insect must be considered separately in studies of insect resistance. This is not always easy to do under field conditions. Immature stages of insects frequently cannot be identified except after rearing to the adult stage. The larvae and pupae of the southwestern corn borer cannot be distinguished from the southern cornstalk borer, yet the two insects appear to be very different in their potential destructiveness to the corn crop. The abundant leafhoppers of the genus *Empoasca*, some of which cause hopperburn of potatoes and alfalfa yellows, are distinguishable largely on the basis of internal male sex organs or genitalia, yet different species of this genus are very different in their food habits and destructiveness to food plants (12).

The fact that a plant variety is resistant to one species of aphid is by no means evidence that it will be resistant to other aphids. This has been amply demonstrated (17) in the case of the aphids of raspberry where varieties resistant to *Amphorophora rubi* Kalt. have not been resistant to the other species of aphids feeding on raspberry. The assumption that varieties resistant to one species of insect will also be resistant to a related insect has sometimes been made and may be responsible for errors in results reported in the literature on insect resistance.

Related to this problem is that of the presence of biotypes of insects within a single species and differing in food habit. These biotypes may be responsible for differences in results when resistant varieties are tested in various regions. Perhaps because of the newness of any widespread testing of varieties for insect resistance only a few such

cases have been studied, but the presence of biotypes must be taken into consideration. The not infrequent occurrence of insect biotypes has been reported (4, 15). Such biotypes within species may be of two general kinds, *viz.*, a mutant form attuned to a particular feature of the environment or groups of individuals inherently vigorous and able to survive various kinds of adverse conditions. Distinction must be made between inherent biotypes and variations resulting from degree of infestation and the effect of environmental conditions either on host plant or insect.

## HABITS AND LIFE HISTORY IN RELATION TO RESISTANCE

One of the difficult phases of insect resistance studies has been the production of consecutive satisfactory insect populations in test plots. This sometimes involves opposite considerations from those that usually motivate the economic entomologist. Continuous studies involve either taking the plant varieties to the insect, or bringing the insect to the plants in the laboratory, greenhouse, or restricted field tests. Each of these methods should have its place in any insect resistance program, for while intensive laboratory methods may not reveal the economic possibilities of lower degrees of resistance, field studies may not reveal escapes, differences in degrees of resistance, and other sources of error which should be known to the investigator. These studies need detailed knowledge and sometimes research on the habits and life history of the insect being used. Of course, it is the particular problem of entomologists to produce satisfactory infestations. This may not mean the largest possible populations, but rather controlled populations. Because resistance is so often relative, various intensities of infestation are needed. For plant breeding work that infestation is best which gives the maximum difference between the resistant and the susceptible parents. For testing of new varieties the widest range likely to be available under farm conditions is necessary. Advantage should be taken of insect outbreaks in securing data on resistance.

Differential or changing abundance of insects, coupled with the fact that resistance is relative, may complicate genetic interpretation, especially when based on percentages of plants killed or similar criteria. This has been suggested in the case of chinch bug resistance in sorghum (13) and again in the case of resistance of Marquillo wheat hybrids to Hessian fly (10). In the segregating population of sorghums reported, a count of $F_3$ lines made on July 13 appeared to indicate that resistance was dominant. A classification made 11 days later appeared to indicate that resistance was recessive. During these 11 days the chinch bugs had been feeding and increasing in numbers and size. This perhaps resulted in considerable injury to individual plants heterozgous for resistance. A similar apparent partial shift in dominance as related to intensity of infestation has been noted in various Marquillo wheat hybrids tested for Hessian fly resistance during different seasons and in different places.

The handling of test materials requires a synchronization of insect life history with suitable stages in the life history of the plant. Since

the corn ear worm is attracted to corn silk for oviposition, corn hybrids being tested for resistance to this insect ordinarily should be planted at a time when they will come in silk during the period of maximum egg laying of this insect. Adjustments in planting date to offset differences in inherent maturities, where possible, are preferable to statistical adjustments. Hand infestations of individual plants and individual plant and insect life history records are time-consuming and limit the total number of strains which may be studied, but under certain conditions they are necessary and have frequently given valuable information. The stage in the insect life history to be used in manual infestations must be dictated by a knowledge of that insect.

The result of insect resistance studies are sometimes influenced by the fact that the insect uses a part of the food plant for shelter during feeding. The relation of loose or tight sorghum leaf sheaths to chinch bug resistance has been pointed out (13). The leaves of most varieties of onions fit closely together near the base and this area is a favorite feeding place for the onion thrips. The onion variety White Persian has leaves which do not fit so closely together and there is experimental evidence (6) that this growth habit is one factor in the resistance of that variety. The long tight husks of corn ears have frequently been mentioned in connection with resistance to corn ear worm and Barber (1) has shown that this is brought about because the cannibalistic tendencies of the larvae are allowed full play in the confined shelter of the husks. Thus, various tropisms of insects must receive considerable attention in resistance studies.

## SUMMARY

A number of facts in the relation of insect habits and physiology to the resistance of plants to insect attack have been discussed. Others could have been mentioned. In studies of insect resistance one or more of the relationships discussed will be found of importance. In spite of the complexity of some of the problems much progress has already been made in the breeding of plants that are resistant to insects. For further progress it will often be necessary to give increasing attention to the intimate details of insect and plant biology and genetics.

The great number of insects and the endless variety of their adaptations to plant life complicate the difficulties in drawing conclusions about the relationship of insect physiology to the causes of resistance. Yet recent studies (9) have shown the importance of three insect-plant relations in many cases of insect resistance. These are tolerance in the plants and preference and antibiosis in the insects. The latter term refers to any adverse effect on the insect resulting frequently from the use of resistant plants as food. Studies of both preference and antibiosis involve a knowledge of insect physiology and habits.

A knowledge of insect physiology, tropisms, and life history is necessary in any extended breeding program for resistance to insects. Such information will aid in the search for and understanding of the causes of resistance. Without such knowledge one may be more easily misled in respect to type of insect damage, presence of plants that

escape infestation, the correct interpretation of experiments, and statistical analyses. Information on insect life history is needed in the planning of infestations of controlled intensities. The correct identification of the insect, including possible biological races, should receive adequate attention.

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## NOTES

### ABNORMAL LEAF FORMATION ON FLAX SEEDLINGS CAUSED BY SPERGON[1]

ABNORMAL leaves on flax seedlings grown from seed treated with "Spergon" were first observed in nursery plantings[2] made at Pullman, Washington, in the spring of 1942. Bison and Redwing flax were treated with 2 ounces of Spergon per bushel and seeded on April 6. On May 10, approximately 80% of the seedlings showed abnormal leaves. Seedlings made in the same manner on April 18 and 20 had approximately 30% seedlings with abnormal leaves.

The abnormality consisted of apparent lateral fusion of two to six leaves at the same node as shown in Fig. 1. Such fusion occurred in

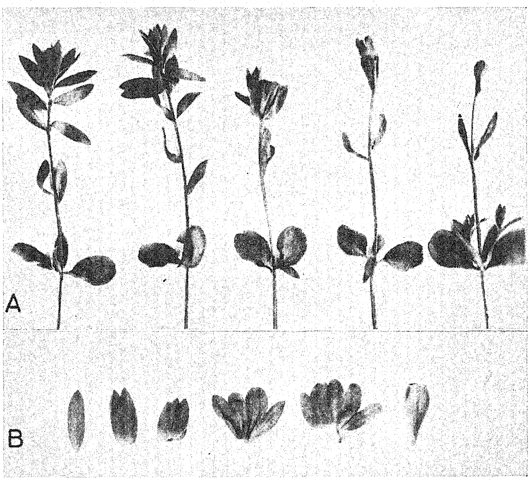


FIG. 1.—A, flax seedlings showing, from left to right, normal leaves, a double leaf, a large abnormal leaf, a tubular leaf, and a tubular leaf enclosing an injured apical bud as indicated by the lateral shoot development at the cotyledons. B, flax leaves showing varying degrees of fusion in abnormal leaves.

[1]Published as Scientific Paper No. 557, College of Agriculture and Agricultural Experiment Station, State College of Washington, Pullman, Wash.

[2]Field observations were taken from plantings made by O. A. Vogel, Associate Agronomist, Bureau of Plant Industry, U. S. Dept. of Agriculture.

varying degrees. The most extreme case was a leaf which formed a complete tube around the stem with the apical bud inside. In some cases the number of lobes on the tube gave little indication of the number of leaves involved in the abnormal development. In other seedlings the lobes were quite distinct with some very deep clefts extending almost to the stem. In the majority of instances a tube was not formed, but one or more large leaves with two to six lobes occurred. Abnormalities usually were found from the fifth to tenth leaves above the cotyledons. This agrees with the work of Crooks[3] who noted occasional double leaves occurring naturally within this region of the flax seedling.

Redwing flax seed treated with Spergon at different rates was seeded in the greenhouse April 17, 1943. Data taken on May 5 corroborated those from previous tests made with five other varieties and are shown in Table 1. As the rate of treatment increased, the frequency and degree of abnormality in the leaves also increased. Likewise, with an increase in Spergon application fewer normal leaves were produced between the cotyledons and the first abnormal leaf. It also was observed that there was greater elongation of the first internodes in those seedlings which exhibited a marked abnormality or definite injury. The first internode is normally less than 1 mm long, but in an occasional plant from seed treated at the rate of more than 3.6 ounces of Spergon per bushel, the first leaf was tube shaped and the internode was 15 to 20 mm long.

FIG. 2.—The tops of three flax plants showing abnormal leaves produced by application of Spergon to apical buds of seedlings. Left to right, normal leaves, large abnormal leaves, and a tubular leaf.

A small quantity of Spergon was applied directly to the apical buds of 2-week-old flax seedlings to determine the effect it might have on the plants. No effect was apparent for 2 weeks during which time the plants grew an additional 6 to 8 inches in height. At this point abnormal leaves, similar to the ones produced on the young seedlings, appeared as shown in Fig. 2.

The plants in the field on which abnormal leaves occurred grew adjacent to plants grown from seed treated with "New Improved Ceresan" and untreated seed in connection with seed treatment tests designed to determine control

[3]CROOKS, DONALD N. Histological and regenerative studies on the flax seedling. Bot. Gaz., 95:209–239. 1933.

TABLE 1.—*Summary of data taken in greenhouse on abnormal leaf development on flax seedlings grown from seed treated at different rates with Spergon.*

| Spergon treatment, oz. per bu. | Total number of plants | Number of plants with abnormal leaves | | Percentage of plants with abnormal leaves | Location of abnormal leaves on seedling (counting leaves above cotyledons) |
|---|---|---|---|---|---|
| | | Double leaves | Larger leaves | | |
| None | 84 | 1 | 0 | 1 | 6 |
| 0.6 | 122 | 10 | 1 | 9 | 7 to 10 (12)* |
| 1.2 | 148 | 12 | 4 | 11 | 6 to 10 |
| 1.8 | 135 | 17 | 10 | 20 | 5 to 9 |
| 2.4 | 170 | 19 | 29 | 28 | 5 to 10 |
| 3.6 | 196 | 31 | 52 | 42 | 5 to 9 (14) |
| Excess | 101 | 9 | 59 | 67 | 1 to 7 |

*Figures in parentheses represent one seedling.

measures for pre-emergence damping-off and seed decay resulting from cracked seed coats. Abnormal leaves were found only on the seedlings from Spergon-treated seed. At first there was a distinct difference in appearance between the rows having abnormal seedlings and rows from the other two treatments. This difference in appearence soon was outgrown and there was no further effect on the plants as far as subsequent growth or yield were concerned.

In view of the work of Crooks in his ontogenetic study of the flax leaf, it is suggested that Spergon strengthened the tendency of the apical primordia of some seedlings to differentiate leaf primordia in groups of two to six instead of singly. The action of the Spergon seemed to be limited to the primordial cells of the stem tip. Those tissues which already had been differentiated to some extent continued development. Spergon applied so that it could reach the apical primordium in an excessive amount apparently prevented further differentiation of leaf or stem primordial cells on the main shoot. New stems soon developed from lateral buds (Fig. 1 A).

These experiments were made with machine-threshed seed which was observed under magnification to have small cracks or open breaks in the seed coats of 65 to 75% of the seed. These seed coat injuries would provide an avenue of entrance by which the Spergon could reach the epicotyl in sufficient concentration to cause abnormal leaf development before the seed coat which held the Spergon was sloughed off in the process of emergence from the soil. This might explain the wide variation in the response of different seedlings in the same rate of treatment.—DWIGHT D. FORSYTH, *Seed Analyst, Department of Agronomy, State College of Washington, and* MAX L. SCHUSTER, *Research Fellow, Division of Plant Pathology, Washington Agricultural Experiment Station, Pullman, Wash.*

## BARLEY VARIETIES RESISTANT TO STRIPE, *HELMINTHOSPORIUM GRAMINEUM* RABH.

INFORMATION on varietal resistance to this important barley disease, and on an easy method for appraising such resistance, seems timely in view of the current importance of increased production and the conservation of mercury and copper dusts now used for its control. The technic for obtaining infection is a round-about method resorted to only because no effective, simple, seed inoculation method is known. It involves use of male-sterile plants on which the wide-open flowers on entire spikes are dusted with spores immediately following mass pollination.[1] Since the male-sterile stock is very susceptible to stripe, resistance of the pollen parent may express itself in the progeny. Preliminary results, as shown in Table 1, suggest three genetic groupings of varieties based on the performance of their $F_1$ progeny, *viz.*, (1) resistant, with dominance nearly complete; (2) intermediate resistance or incomplete dominance; and (3) susceptible or dominance of susceptibility.

TABLE 1.—*Comparative resistance of certain barley varieties to a single culture of the stripe fungus as determined by their $F_1$ progeny responses.*

| Pollen parent | C.I. No. | Infection in $F_1$ progeny of crosses with male sterile plants | | | |
|---|---|---|---|---|---|
| | | 1942 | | 1943 | |
| | | Number of plants grown | Diseased plants, % | Number of plants grown | Diseased plants, % |
| Vaughn | 1367 | 121 | 4.5 | 101 | 4.1 |
| Hannchen | 531 | 32 | 28.1 | 41 | 4.9 |
| Wisconsin Barbless | 5105 | — | — | 75 | 5.3 |
| Arivat | 6573 | — | — | 49 | 8.2 |
| Trebi | 936 | 9 | 33.3 | 119 | 24.4 |
| Coast (Winter Tenn.) | 4633 | — | — | 41 | 39.1 |
| Hero | 4602 | — | — | 24 | 50.0 |
| Atlas | 4118 | 31 | 41.9 | 27 | 55.6 |
| Rojo | 5401 | — | — | 76 | 63.2 |
| Comp. Cross sel. | 5368* | — | — | 157 | 72.0 |
| Colsess V | 5987 | 14 | 78.6 | 8 | 75.0 |
| California Mariout | 1455 | — | — | 36 | 80.5 |
| Club Mariout | 261 | — | — | 37 | 81.1 |
| Manchuria | 2947 | — | — | 22 | 95.5 |

*Fertile prototype of male sterile.

In the experiments herein reported, susceptibility in plants first became evident 5 weeks before heading and in no case did these plants produce viable seeds. The stripe culture used for these tests traces to spores from a single plant. The groupings mentioned above have confirmation in earlier California tests involving fewer varieties in

[1]SUNESON, C. A., and HOUSTON, B. R. Male-sterile barley for study of floral infection. Phytopath., 32:431–432. 1942.

which infections were obtained by sprouting seeds on a media base supporting mycelial growth or by growing the varieties under conditions favorable for natural infection. In these early tests resistant Vaughn never showed more than 5% stripe; the less resistant Coast (Winter Tennessee) never more than 15%; and Atlas a universal susceptible reaction. If these earlier tests are reliable, California Mariout is resistant, but susceptibility is completely dominant when crossed with male-sterile. On the other hand, the difference in reaction may be due to a difference in strains of the inoculum, since the inoculum in the present tests is not known to be identical with that used earlier. In the North Central states, Dickson[2] lists Wisconsin Barbless and Trebi among the most resistant varieties grown.

From the results at hand it seems reasonably certain that the varieties Vaughn, Arivat, Wisconsin Barbless, Trebi, Coast (Winter Tennessee), and Hannchen are sufficiently resistant to stripe to permit their wartime cultivation without seed treatment, if the proper dusts are not available. Exclusive of Wisconsin Barbless, these varieties are now grown on about 1,000,000 acres in California and bordering states.—COIT A. SUNESON and SYLVIA C. SANTONI, *Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the Department of Agronomy, University of California, cooperating.*

[2]DICKSON, J. G. Outline of Diseases of Cereal and Forage Crop Plants. Burgess Pub. Co. 1939.

# BOOK REVIEW

## THE CHEMICAL FORMULARY

*H. Bennett, Editor-in-Chief. Brooklyn: Chemical Publishing Company. Vol. VI. XVIII+636 pages. 1943. $6.*

THE thousands of recipes and formulas given in the present volume are all new and complement admirably the contents of previous volumes. After a general discussion of the art of compounding, the chapters deal with adhesives, beverages, cosmetics and drugs, emulsions, farm and garden specialties, food products, hides, leather and fur, inks and marking materials, lubricants and oils, materials of construction, metals and alloys, paints, varnishes, laquer and other coatings, paper, photography, polishes and abrasives, pyrotechnics and explosives, rubber, resins, plastics and waxes, soaps and cleaners, textiles and fibers, and miscellaneous formulas.

The list of substitute materials, various tabulated information and the 47 pages of indexes make this volume practically a handbook. The up-to-date character of most information is a tribute to the editor and his collaborators. No doubt, the Formulary is slowly becoming a "must" for technical libraries and no one concerned with science or technology will deny the usefulness of these volumes.—(Z. I. K.)

# AGRONOMIC AFFAIRS

## ROADSIDE MARKERS

ACTING upon a suggestion made by D. Howard Doane at the meeting of the Soil Science Society in St. Louis last fall, President Firman E. Bear has named a committee on roadside markers to consider ways and means of placing markers at conspicuous points along highways to locate important soil types. The committee is as follows: E. D. Fowler, *Chairman*, T. M. Bushnell, M. G. Cline, G. W. Conrey, H. J. Harper, J. R. Henderson, W. M. Johnson, R. J. Muckenhirn, S. S. Obenshain, R. S. Smith, R. E. Storie, and M. B. Sturgis.

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# THE CAGE METHOD FOR DETERMINING CONSUMPTION AND YIELD OF PASTURE HERBAGE[1]

DAYTON L. KLINGMAN, S. R. MILES, AND G. O. MOTT[2]

NUMEROUS investigators in pasture research are using cages as a means of measuring the *production* of pasture herbage. A few are using the method to determine the *consumption* of pasture herbage by livestock. Some investigators have considered the method very inadequate and have not adopted it or have discarded it after a short trial. In experiments in Indiana, cages have been used for several years to measure production and consumption of pasture herbage. The data obtained have been very helpful in interpreting the gains in weight made by sheep and beef cattle and the milk production of dairy cows when grazing on various types of pasture.

Variations in the cage method have received considerable study at the Purdue University Agricultural Experiment Station during the past two years.

The purpose of the work reported here was to compare the precision resulting from a random choice with that from a selected choice of the second of the two areas to be clipped for estimating consumption by the difference method.[3] The use of duplicate cages and differences among operators were also investigated.

Vinall[4] states that it is desirable to measure the production of grazed plots by mowing representative areas protected from grazing. He says also, "There are two methods of arriving at yields. One attempts to measure the herbage consumed by the grazing animals; the other measures the annual growth of herbage, or that available for grazing."

The first method assumes that the difference in yield between a protected and a nearby grazed area is equal to the herbage consumed. The protected area is relocated at the beginning of each grazing

[1]Journal Paper No. 87, Purdue University Agricultural Experiment Station, Lafayette, Ind. Contribution from the Department of Agronomy. Received for publication March 6, 1943.

[2]Graduate Assistant, Associate in Agronomy, and Associate in Pasture Research, respectively. Based on data presented by the senior author in partial fulfilment of the requirements for the degree of master of science, May 1942.

[3]FUELLEMAN, R. P., and BURLISON, W. L. Pasture yields and consumption under grazing conditions. Jour. Amer. Soc. Agron., 31:399–412. 1939.

[4]VINALL, H. N. Pasture research. Jour. Amer. Soc. Agron., 26:1027–1030. 1934.

period. In the second method, the annual growth or production is the total yield obtained by clipping the same protected area throughout the season. The difference method of measuring consumption may have certain advantages over the above-described method of measuring the annual growth in that for the difference method the growth conditions of the grass within the cage more nearly represent those of the grass under actual grazing conditions. In connection with the difference method it is possible, also, to calculate the herbage available for any grazing period and the season's production. The season's production is equal to the season's herbage consumption plus the aftermath remaining at the end of the grazing season.

## EXPERIMENTAL PROCEDURE

The field work for this study was all done on July 11, 1941, in a 12-acre permanent pasture at the experimental livestock farm located north of West Lafayette, Ind. At that time, the pasture had been grazed by 14 beef cows since the last of April. Although the pasture had been heavily stocked, small patches of Kentucky bluegrass and timothy were left ungrazed. The closely grazed portions contained considerably more white clover and Canada bluegrass than the lightly grazed portions. No botanical analysis was made of the herbage.

Four workers—two experienced and two inexperienced, working independently—performed the experiment after receiving careful instructions as to procedure.

The cages used in pasture experiments at this station protect an area 4 by 4 feet. Any area of this size is referred to in this paper as a *unit*. Each "caged" unit was located at *random* by tossing a short stake and was designated as a C unit (C for caged). No cages were actually placed, however. Two "uncaged" units were next chosen within 6 to 15 feet of the caged unit. One of these was *selected* as being *similar* to the C unit in plant composition, amount of growth, and soil characteristics, while the other was chosen at random. The *similar* unit was called an S unit (S for similar) and the *random* uncaged unit was designated as an R unit (R for random).

A local area, which in this study was sampled by a set of three units (one each of C, S, and R), is designated as a *station*. Since there were 80 stations well distributed over the 12-acre pasture, the stations averaged 0.15 acre in size and about 80 feet from "center" to "center". Each of the four operators harvested 20 stations (60 units) scattered over the entire pasture.

The three units of a station were harvested immediately after selection. The operators clipped the herbage as close to the ground as possible with Wiss grass shears, weighed it, and took a moisture sample promptly upon harvest.

In this paper, *yield* means the weight of dry matter in the herbage clipped from either a caged or an uncaged area, while *production* is the yield from a caged area at the end of a grazing period, a grazing period being the number of days from the time a cage is placed until it is removed and the herbage under it is cut. In other words, *production* is the amount of dry matter which would have been available to livestock during the period if there had been no cage. Since, in this technic study, harvesting followed immediately the choosing of the units, the length of the grazing period was zero and *production* is properly estimated from R as well as from C units, both of which were chosen at random. *Consumption* is the yield of a caged unit minus the yield of the companion uncaged unit. All yield, production, and consumption figures are stated as pounds of dry matter per acre.

## RESULTS

### SIMILAR VERSUS RANDOM UNITS

Since there was no grazing in this pasture between the selection and the harvesting, the consumption is known to be zero. Each difference between a C and its R unit or between a C and its S unit is therefore entirely an error in the estimate of zero consumption. The standard deviation of the errors is 378 pounds per acre when the R units were used but only 134 pounds when the S units were used. Every one of the four operators was able to reduce the experimental error greatly by selection.

When estimates of consumption are actually being made there are two sources of error. One is the fact that grazing is not uniform, while the second is the variation in soil and herbage between the caged and the uncaged units at the beginning of the period for which consumption is estimated. The error due to the first source is uncontrollable, but the results indicated above show that men can considerably reduce the error due to the second source by selecting the second unit similar to the first—the first having been chosen at random. This selection must be made when the cage is placed and the location of the uncaged unit must be marked or recorded in such a manner that it can be definitely identified at the end of the grazing period. If the place is marked, care must be used that the marking will have no effect on the grazing.

The variance (square of the standard deviation) of the errors in the estimates of consumption using R units is 7.96 times that using S units. This indicates a very highly significant difference. At first thought this fact might lead to the conclusion that, for equal precision, 8 times as many cages would be needed if both of the units needed to estimate consumption were chosen at random as if only one were chosen at random and the second were selected. This is not the case, however, because increasing the number of cages decreases the error due to nonuniform grazing as well as that due to differences between the caged and the uncaged units. From this research no definite estimate can be made as to the relative numbers of cages needed with the two methods. However, it is true that, for equal precision, the method of selection requires fewer cages than the method of random choice of both units; or, in other words, an equal number of cages will give more reliable estimates of consumption with the selection method.

A study is now under way to estimate the relative number of cages needed for the two methods to attain equal precision.

### NUMBER OF CAGES

Some researchers have used "duplicate" cages in estimating production or consumption. This means placing cages in pairs with the members of pairs rather close together but the pairs well distributed over the pasture. A study was made of the precision of production estimates with cages placed singly, in pairs, and in trios.

To measure production, all units should be located at random, which was the case for the C and R units. The data from only these

two kinds of units were used in this part of the study. A C and its R unit averaged about 10 feet apart, while pairs (station "centers") averaged about 80 feet apart. From the production data, the variation was estimated for *between units within stations*, for *among stations*, and for *among operators*. The analysis of variance is given in Table 1. It is seen that the variation among stations is significantly greater than that between units. From the variances (mean squares), estimates can be made of the number of cages needed to obtain a chosen precision when the cages are placed singly, in pairs, or in trios.

TABLE 1.—*Analysis of variance for production.*

| Variation | Degrees of freedom | Mean square | F |
|---|---|---|---|
| Total | 159 | —— | —— |
| Among operators | 3 | 1,273,642 | 4.07** |
| Among stations of same operator | 76 | 313,172 | 4.40** |
| Between units within stations | 80 | 71,244 | —— |

**Significant at the 1% level.

To make such estimates let

$V_u$ = the variance of units within stations

$V_s$ = the net variance for stations—the variance for units and operators having been excluded

k = the number of units per station

n = the number of stations

N = nk = the total number of units (or cages—since every unit is caged in production estimation)

t = standard measure, (t = 2, approximately, at the 5% level of probability)

E = the error to be tolerated at the chosen level of probability. For example, if we choose E as 100 pounds per acre at the 5% level, we wish only 5% of the mean estimates of production (if many estimates were made) to deviate as much as 100 pounds from the true production.

Now let us make estimates of the true values of $V_u$ and $V_s$, using data from Table 1. The estimate of $V_u$ is 71,244. $kV_s+V_u$ = the variance among stations in Table 1. Substituting, $2V_s+71{,}244 = 313{,}172$ and $V_s = 120{,}964$.

Using these estimates, we next estimate the number of cages for chosen values of E by means of the formulas

$$n=\frac{t^2}{E^2}\left(V_s+\frac{V_u}{k}\right), \text{ and } N=nk.$$

For E = 100, t = 2 (the 5% level), and one cage at a place (k = 1),

$$n=\frac{4}{10{,}000}(120{,}964+71{,}244)=77, \text{ and}$$

$$N=nk=(77)\,(1)=77.$$

For the same values of E and t and for cages in trios ($k=3$),

$$n=\frac{4}{10{,}000}\left(120{,}964+\frac{71{,}244}{3}\right)=58, \text{ and}$$

$$N=nk=(58)\ (3)=174.$$

Similar calculations gave the numbers in Table 2. This table gives the estimated number of cages needed to attain selected degrees of precision, in estimating production, when cages are placed 1, 2, or 3 at a station.

It is noted from Table 2 that, to estimate the production of a pasture, the most efficient use of *cages* is to place them singly; furthermore, this is certainly advisable since the time and cost per cage is about the same regardless of whether the cages are placed singly or in groups. With trios it is necessary to use 2.26 times as many and with pairs 1.63 times as many as with single cages. If the researcher wished to use only about 20 cages, the expected error at the 5% level is approximately 200 pounds per acre with single cages, 250 pounds with pairs, and 300 pounds with trios.

Table 2 applies strictly only to pastures with the same station-to-station and unit-to-unit variability as this pasture. However, the principle holds universally that the most efficient method is to place cages singly for production or consumption estimates, so long as the cost per cage is the same regardless of whether the cages are grouped.

TABLE 2.—*Number of cages necessary to measure production of the pasture in this study with a desired precision at the 5% level of probability, using one, two, or three cages per station.*

| Precision desired* | Cages placed | | |
|---|---|---|---|
| | Singly | In pairs | In trios |
| 50 | 308 | 502 | 696 |
| 100 | 77 | 126 | 174 |
| 150 | 34 | 56 | 78 |
| 200 | 19 | 32 | 45 |
| 250 | 12 | 20 | 30 |
| 300 | 9 | 14 | 21 |
| 400 | 5 | 8 | 12 |
| 500 | 3 | 6 | 9 |

*Precision is in pounds of dry matter per acre. See E in the list of symbols for further explanation.

Let us now consider the number of stations to sample in order to attain a desired precision after it has been decided how many cages to place per station. Column 2 of Table 2 gives such figures for cages placed singly. For calculating these numbers it was assumed that the station-to-station variance would remain constant regardless of the number of stations sampled. This assumption must usually be made for such computations, although it does not always hold. As the number of stations sampled increases they are necessarily closer together in any given pasture and the variation among them may decrease. In fact, if the stations are so numerous that they are very

close, their variance is almost certain to be less than if they are far apart. In that case the calculated number is excessive. If most of the area of a pasture were taken in the samples, the precision of the estimate would be much greater than the calculation, based on the aforementioned assumption, would indicate. In the limiting case in which so many "samples" are taken that the entire pasture is harvested, there is no *sampling* error in the *yield* of that pasture and it is determined with perfect precision, except for errors due to such causes as imperfect weighing and failure to cut and collect all the herbage.

Considerations such as those of the last paragraph have a bearing on the comparative numbers of cages needed in large and small pastures for estimating either production or consumption. If the station-to-station variability for the entire pasture is equal for both a large and a small pasture, the same number of cages is needed for each in order to attain equal precision. But with a considerable increase in the number of stations, the precision would likely increase more rapidly in the smaller pasture because the station-to-station variation would probably decrease faster in it. In this study it was found that the variability was only slightly greater for the entire 12-acre pasture than for much smaller areas in it. It is concluded that if the pasture had been only 2 acres in size, say, practically as many cages would have been necessary as for the entire 12 acres for equal precision in measuring production. Experience in Indiana indicates that this is not an infrequent occurrence.

## DIFFERENCES AMONG OPERATORS

It is of some importance to compare the results of different individuals doing the sampling in order to know whether it is satisfactory to use more than one operator and whether the results of different men are comparable.

Table 1 shows that operators differed very significantly in their estimates of production. Table 3 gives these estimates. The differences between operators were due to differences in the heights at which the herbage was cut. Operator A (experienced) noticed that operator C (inexperienced) was not clipping the grass nearly close enough to the ground when they both had about one-half of their areas clipped. He instructed operator C to continue clipping in the same manner, however, so the data would be consistent—consistently low. This fact accounts entirely for the differences among operators. This is shown by a more detailed analysis than that in Table 1. This detailed analysis showed that A, B, and D differed less among themselves than would be expected, judging by the experimental error, but that operator C's production estimate was very significantly lower than the average of the yields of the other three. Because of this bias, the production estimates of operator C were not included in the averages in the last line of Table 3.

A consistent under-estimate of production would be serious if the true production were of importance, but if it is desired only to compare the production in different pastures or plots, under-estimates would probably be unimportant, provided clipping was at the same

height in all pastures and was low enough to get some of every blade of grass, because the differences between pastures would probably be affected only very slightly.

TABLE 3.—*A comparison of the estimates of production and of consumption made by four persons based on pounds of dry matter per acre.*

| Operator | Production estimates | | | Consumption estimates* | | | |
|---|---|---|---|---|---|---|---|
| | | | | Using R units | | Using S units | |
| | Using C units | Using R units | Average | Consumption* | Significant difference† | Consumption* | Significant difference† |
| A | 601 | 526 | 563 | 75 | 171 | 19 | 56 |
| B | 660 | 809 | 734 | −149 | 221 | 4 | 67 |
| C | 343 | 376 | 359 | − 33 | 105 | 33 | 33 |
| D | 716 | 753 | 734 | − 37 | 189 | − 5 | 87 |
| Average | — | — | — | 74 | — | 15 | — |
| Av. for A, B, D | 659 | 696 | 677 | — | — | — | — |

*The true consumption is known to be zero in this experiment.
†At the 5% level.

Table 3 also gives information concerning estimates of consumption, which is known to be zero. When the R units were used in estimating consumption, no operator obtained an estimate which even approached a significant deviation from the true value. However, the errors of estimation were rather large. They varied from 33 to 149 pounds and averaged 74 pounds, disregarding algebraic signs. On the other hand, when the S units were used, the errors were small. They varied from 4 to 33 pounds and averaged 15 pounds. The largest error by this method was the same size as the smallest when the uncaged units were chosen at random. These facts reemphasize the greater accuracy of the method in which one of the two units needed to estimate consumption is selected similar to the other which is first chosen at random.

Turning to a consideration of the consumption estimates made by the use of the S units, it is noted that the estimates of three operators, namely, A, B, and D, did not approach a significant deviation from the true consumption of zero. It will be remembered that the same was true for all four operators when using R units. However, when using S units the estimate of operator C, was significantly in error. Further evidence that his estimate was biased in a positive direction is the fact that only 3 of his 20 estimates were negative. There is little doubt that in his selection of an S unit similar to a C unit he tended rather consistently to select an S unit lower in yield than the C unit. To avoid bias in the mean estimate due to such a tendency, an operator should select a unit at random and its mate to be similar, then by tossing a coin should decide which unit is to be caged. In this study the yield of the S unit was always subtracted from that of the C unit.

It is assumed that small errors of estimate for an operator are due to his clipping different units at a uniform height. It was very interesting to find from the data that operator C was significantly more consistent in his height of clipping of all three kinds of units than any other operator. In other words, his errors of estimate were smaller whether using an R unit or an S unit along with the corresponding C unit to estimate consumption. This fact was surprising because he was inexperienced and because he clipped rather high. Contrary to what was found, it would seem that a person who clips high could not clip at as uniform a height as one who clips as close to the ground as possible. Another point of interest brought out by the work of operator C is that the ability to clip at a uniform height may be independent of skill in selecting one unit similar to another. Operator A, who was experienced, was second most accurate in clipping at a uniform height.

Since men vary in their work, all operators should work in each pasture if treatments are not replicated. If treatments are replicated, each man may handle a replicate. Either of these procedures avoids bias due to confounding operator with treatment.

The differences among operators need cause no apprehension concerning the value of results when several workers must be used, so long as those workers make a sincere effort to follow instructions. The workers must be used properly, however.

## SUMMARY

A study of certain phases of pasture research methods using cages has led to the following conclusions:

1. For estimating consumption by the difference method, it is more efficient to choose one unit at random and the second similar to the first than to choose both at random. After the two units are chosen, a coin should be tossed to decide which unit to cage. Each of four operators increased precision considerably by selection of the second unit.
2. It is more efficient to place cages singly than in groups.
3. For pastures with equal station-to-station variability, the same number of cages is needed for equal precision in estimating the production or consumption of the entire pasture, regardless of the size of the pasture. In the pasture studied, nearly as many cages would be needed for a 2-acre area as for the entire 12 acres.
4. It was found that men differ in their work, but the differences need cause no apprehension concerning the value of results when several workers must be used so long as those workers make a sincere effort to follow instructions. The workers must be used properly, however. Some suggestions are made regarding the use of workers.

# FERTILIZER PLACEMENT STUDIES ON HILLSDALE SANDY LOAM SOIL[1]

A. G. WEIDEMANN[2]

DURING the last decade there has been an ever-increasing interest in the problem of how best to apply fertilizers to obtain maximum crop response and the most economic returns for the money spent. To supply answers to these questions, a rotation experiment was started on the farm of Michigan State College, East Lansing, Mich., in 1931, which involved the placement of a 2–12–6 fertilizer for corn and wheat in various locations with reference to the seed. Use was also made of stable manure, both alone and reinforced with superphosphate. Later there were added to the experiment comparisons of 2–12–6 with 0–12–6 fertilizer, and of a heavy application of phosphate and potash plowed under for corn with the same amounts of these elements plus 500 pounds of calcium cyanamide.

The rotation consisted of corn, barley, wheat, and clover. Pickett's yellow dent, an adapted, open-pollinated variety of corn was used. The clover sod was spring plowed for corn and the barley ground was plowed for wheat. The seedbed for barley was prepared by disking.

The experiment was conducted on Hillsdale sandy loam, a soil type which occupies large areas in south central and southwestern Michigan. Although this soil type is characterized by the presence of calcareous rocks of various sizes scattered throughout the profile, the soil itself is generally too acid to grow alfalfa or clover well. On the experimental field this condition was corrected by the application of liming material.

## REVIEW OF LITERATURE

No attempt will be made to review the extensive literature dealing with the placement of fertilizer for corn and the effect of fertilizer on the other crops grown in the rotation. However, few studies have come to the attention of the writer concerning methods of applying fertilizer for wheat. Reference is made to several experiments with corn which touch on points mentioned specifically in this study.

Salter and associates (4)[3] found that delayed applications of 2–12–6 beside the corn rows or hills were less effective in 1937 than applications made at planting time. However, in 1938 and 1939 the treatment which gave the largest increase in yield consisted of applying one-third of the fertilizer (150 pounds) at planting time, one-third at the first cultivation, and one-third at the time of last cultivation.

Miles (3) found that over a period of years small amounts of fertilizer applied near the seed gave better results with corn than fertilizer applied by other meth-

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[3]Figures in parenthesis refer to "Literature Cited", p. 766.

ods. Cook (1), on the other hand, obtained very satisfactory increases in yields of corn on several heavy soil types in Indiana by plowing under from 100 to 500 pounds of cyanamide and supplying phosphate and potash. Scarseth and associates (5) also report appreciable increases in yields of both grain and stover, when moisture supply was adequate, from plowing under varying quantities of sulfate of ammonia and drilling 0–12–12 or 3–12–12 fertilizer at planting time. Additional nitrogen applied as a side dressing was sometimes beneficial. The soils used were deficient in nitrogen.

Wiancko (6) and Williams (7) have pointed out that favorable growing conditions during the early part of the season are conducive to the development of suckers on corn, as is also increased soil fertility. In the case of drought in July and August, Williams opined that the yield of corn is likely to be decreased by suckers, unless they are removed. Dungan (2) found corn on fertile Illinois soils, which had produced many suckers, suffered severely in drought periods. When the leaves were removed early in the season from plants which had developed many suckers, the suckers fed the plant and enabled it to produce grain. He concluded that it would be better if plants did not produce suckers, but when they did develop, it was detrimental to the plant to remove them.

## PLAN OF EXPERIMENT

The 88 plots in the experimental field were arranged in four blocks of 22 plots each, in order that each of the four crops in the rotation might be grown every year. The plots were 14 feet by 94 feet which is a convenient size as it will accommodate four rows of corn and two drill widths of small grain. Although the practice of randomizing replicated treatments in different blocks was in use when this experiment was started, its value was not so well recognized as it is at present, hence the older system of having every third plot a check or unfertilized plot without replication of the treatments was followed.

The plan was to apply the fertilizers for corn and wheat and allow the barley and clover to recover as much of the unused fertilizer as they could. There were exceptions to this general procedure, as will be noted in the list of fertilizer treatments. At the beginning of the experiment in 1931, 11 treatments were used with the intervening checks. The rest of the plots were reserved and used later as new ideas concerning fertilizer placement presented themselves.

All fertilizer application rates are given on the acre basis.

Fertilizer "drilled deep, solid" was drilled as deep as possible in 7-inch rows with the fertilizer attachment of a grain drill, previous to planting the seed.

The "in row" placement consisted of dropping the fertilizer near the seed with the attachment on a John Deere planter. In the case of wheat, "with seed" refers to application with a fertilizer attachment of a grain drill at seeding time.

The fertilizer was placed as deep as possible with the corn planter in the method described as "deep with planter before drilling seed," and then the seed was drilled at normal depth in the same rows.

Fertilizer "broadcast and plowed under" was broadcast by hand before plowing, and that "broadcast and worked in" was incorporated with the soil by use of a springtooth harrow after being broadcast by hand on plowed ground.

A fertilizer attachment for a John Deere cultivator was used to place the plant food about 4 inches from the row and behind the first cultivator tooth where it was covered with soil by the second tooth in the "side-dressed with cultivator" method. Fertilizer so placed at the first cultivation is not disturbed by subsequent cultivations farther from the row.

By mixing the fertilizer with a suitable quantity of soil it was possible to apply it by sprinkling 1 pound of the mixture in the bottom of the furrow each time the plow passed across the plot in the "in bottom of furrow" method.

Manure for the experiment was provided in the form of horse manure. The phosphate used to reinforce the manure was equivalent in amount to that contained in 300 pounds of 2–12–6 fertilizer. It was applied broadcast before plowing.

Corn was drilled in rows 42 inches apart with a John Deere Planter sufficiently thick so that it could be thinned to about three plants per 42 inches of row after danger from cutworms and birds was past. No injury to germination from fertilizer was observed.

Wheat and barley were drilled with a standard disk drill at the rate of 1.5 bushels per acre. Clover was drilled with a disk drill as early as one could get on the land in the spring. Manure and sulfate of ammonia top-dressings were applied immediately after the clover was seeded.

Small grains were harvested by cutting an area 10 drill rows wide and 85 feet long from the center of each plot, thus avoiding border effects. The corn from the two center rows of each plot was cut and shocked and allowed to stand for 3 to 4 weeks to dry. The shocks were then weighed and the ears husked and graded into sound, marketable ears and poor or immature ears. Each grade was weighed, the number of ears counted, and samples taken for moisture determination. Yields of stover were calculated on a field weight basis at husking time and of grain on room dry weights. The clover from 2 square rods was weighed when freshly cut and moisture samples taken. Yields are reported on the air-dry basis.

## RESULTS

As the treatments were not replicated, differences in yields due to treatments were calculated by reference to a curve constructed from the yields of check plots. The portion of the curve connecting the points derived from the yields of the nearest check plots was assumed to indicate what the yield of a plot would have been had it been untreated. The yield data are presented in Table 1, and in Table 2 are given the values of the increased yields, the cost of the fertilizers, and the net gains.

### RESULTS WITH CLOVER

The Hillsdale sandy loam does not have a high water-retaining capacity and, as a result, clover seedings in wheat are frequently thin and occasionally fail. When moisture is a limiting factor, fertilizer applications have little value in establishing stands of clover. When a stand is obtained, however, the fertilizer is beneficial to growth as is evidenced by an increased yield for all fertilized plots. The outstanding fact in connection with the clover yields is the large response to manure applications whether they be plowed under for the wheat or applied as an early spring top-dressing. The reasons for this beneficial affect of manure are doubtless due to the fact that clover received no direct fertilization during the hay-producing year and the residual effect of the manure was greater than that of the commercial fertilizer. It is remarkable that the 5-ton top-dressing gave as large yields as the 10 tons plowed under for corn and wheat. This effect may be largely accounted for by the fact that the top-dressing proved highly beneficial in the establishment of seedings. When the clover seeding

TABLE 1.—*Effect of different fertilizers and different fertilizer placement methods on the yield of corn, barley, wheat, and clover.*

| Plot No. | Treatment | | Corn, 11-year av. | | | | Barley, 10-year av. | | | | Wheat, 10-year av. | | | | Clover hay, 10-year av.* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Grain, bu.† | | Stover, lbs. | | Grain, bu. | | Straw, lbs. | | Grain, bu. | | Straw, lbs. | | | |
| | For corn | For wheat | Acre yield | Increase over check | Acre yield | Increase over check | Acre yield | Increase over check | Acre yield | Increase over check | Acre yield | Increase over check | Acre yield | Increase over check | Acre yield, lbs. | Increase over check, lbs. |
| 1 | 300 lbs. 2–12–6 drilled deep, solid | 300 lbs. 2–12–6 drilled deep, solid | 38.34 | 2.94 | 3,750 | 625 | 22.93 | 4.33 | 1,293 | 143 | 30.58 | 4.38 | 2,531 | 421 | 2,245 | 515 |
| 3 | 300 lbs. 2–12–6 broadcast and plowed under | 300 lbs. 2–12–6 broadcast and plowed under | 39.00 | 2.10 | 3,553 | 403 | 22.85 | 4.25 | 1,239 | 169 | 28.54 | 4.14 | 2,204 | 184 | 2,159 | 184 |
| 4 | 200 lbs. 2–12–6 drilled deep, solid<br>100 lbs. 2–12–6 in row | 200 lbs. 2–12–6 drilled deep, solid; 100 lbs. 2–12–6 with seed | 41.42 | 3.52 | 3,898 | 698 | 23.16 | 4.41 | 1,272 | 212 | 31.88 | 8.48 | 2,634 | 654 | 2,441 | 271 |
| 6 | 300 lbs. 2–12–6 deep with planter before drilling seed | 300 lbs. 2–12–6 with seed; top-dressed in spring with 60 lbs. $(NH_4)_2SO_4$ | 44.90 | 5.70 | 4,219 | 879 | 25.38 | 5.48 | 1,384 | 244 | 35.58 | 11.78 | 3,133 | 1,073 | 2,495 | 275 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | None | 300 lbs. 2–12–6 with seed; top-dressed in spring with 5 tons manure | 45.90 | 6.80 | 3,819 | 399 | 27.95 | 7.05 | 1,543 | 323 | 39.74 | 14.94 | 3,865 | 1,685 | 3,117 | 1,042 |
| 9 | 300 lbs. 2–12–6 in row | 300 lbs. 2–12–6 drilled with seed | 40.94 | 2.44 | 4,313 | 913 | 24.25 | 3.65 | 1,374 | 134 | 32.62 | 7.82 | 2,755 | 565 | 2,447 | 497 |
| 10 | 300 lbs. 2–12–6 broadcast and worked in | 300 lbs. 2–12–6 broadcast and worked in | 42.69 | 4.49 | 3,861 | 561 | 25.01 | 5.71 | 1,375 | 215 | 30.09 | 6.59 | 2,595 | 595 | 2,415 | 485 |
| 12 | 300 lbs. 2–12–6 side-dressed with cultivator | 150 lbs. 4–24–12 drilled with seed | 37.73 | 0.83 | 4,025 | 775 | 25.73 | 6.33 | 1,401 | 251 | 30.41 | 7.91 | 2,519 | 569 | 2,254 | 334 |
| 13 | 10 tons manure and 300 lbs. 0–12–0 plowed under | 10 tons manure and 300 lbs. 0–12–0 plowed under | 39.81 | 3.51 | 5,104 | 1,774 | 38.02 | 18.02 | 2,143 | 973 | 40.74 | 17.74 | 3,743 | 1,783 | 2,969 | 1,049 |
| 15 | 10 tons manure plowed under | 10 tons manure plowed under | 38.07 | 2.07 | 5,069 | 1,619 | 38.08 | 18.28 | 2,115 | 965 | 38.54 | 15.04 | 3,593 | 1,623 | 2,839 | 939 |
| 16 | 300 lbs. 2–12–6 in bottom of furrow | 300 lbs. 2–12–6 in bottom of furrow | 35.85 | −0.55 | 4,148 | 673 | 24.63 | 5.33 | 1,257 | 167 | 28.87 | 5.37 | 2,318 | 348 | 2,129 | 229 |

*There was no clover in 1935, 1937, and 1940 due to failure of seedings the preceding years. The averages given here are for seven harvests divided by 10.
†70 pounds of ears taken to equal a bushel in all corn yield calculations.

TABLE 2.—*Economic returns per rotation due to the use of fertilizers and methods of fertilizer placement.*

| Plot No. | Treatment | | Value of increase per rotation* | | | | | | | | Cost of ferti-lizer† | Net gain |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Corn | | Barley | | Wheat | | | | | |
| | For corn | For wheat | Grain | Stover | Grain | Straw | Grain | Straw | Clover hay | Total | | |
| 1 | 300 lbs. 2–12–6 drilled deep, solid | 300 lbs. 2–12–6 drilled deep, solid | \$1.79 | \$0.94 | \$2.34 | \$0.21 | \$3.29 | \$0.63 | \$2.31 | \$11.51 | \$8.40 | \$3.11 |
| 3 | 300 lbs. 2–12–6 broadcast and plowed under | 300 lbs. 2–12–6 broadcast and plowed under | 1.28 | 0.60 | 2.30 | 0.25 | 3.11 | 0.28 | 0.82 | 8.64 | 8.40 | 0.24 |
| 4 | 200 lbs. 2–12–6 drilled deep, solid; 100 lbs. 2–12–6 in row | 200 lbs. 2–12–6 drilled deep, solid; 100 lbs. 2–12–6 with seed | 2.15 | 1.05 | 2.38 | 0.32 | 6.36 | 0.98 | 1.21 | 14.45 | 8.40 | 6.05 |
| 6 | 300 lbs. 2–12–6 deep with planter before drilling seed | 300 lbs. 2–12–6 with seed; top-dressed in spring with 60 lbs. $(NH_4)_2SO_4$ | 3.48 | 1.32 | 2.96 | 0.37 | 8.84 | 1.61 | 1.23 | 19.81 | 9.53 | 10.28 |
| 7 | None | 300 lbs. 2–12–6 with seed; top-dressed in spring with 5 tons manure | 4.15 | 0.60 | 3.81 | 0.48 | 11.21 | 2.53 | 4.67 | 27.45 | 11.70 | 15.75 |
| 9 | 300 lbs. 2–12–6 in row | 300 lbs. 2–12–6 drilled with seed | 1.49 | 1.37 | 1.97 | 0.20 | 5.87 | 0.85 | 2.23 | 13.98 | 8.40 | 5.58 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 300 lbs. 2–12–6 broadcast and worked in | 300 lbs. 2–12–6 broadcast and worked in | 2.74 | 0.84 | 3.08 | 0.32 | 4.94 | 0.89 | 2.17 | 14.98 | 8.40 | 6.58 |
| 12 | 300 lbs. 2–12–6 sidedressed with cultivator | 150 lbs. 4–24–12 drilled with seed | 0.51 | 1.16 | 3.42 | 0.38 | 5.93 | 0.85 | 1.50 | 13.75 | 8.03 | 5.72 |
| 13 | 10 tons manure and 300 lbs. 0–12–0 plowed under | 10 tons manure and 300 lbs. 0–12–0 plowed under | 2.14 | 2.66 | 9.73 | 1.46 | 13.31 | 2.67 | 4.70 | 36.67 | 34.21 | 2.46 |
| 15 | 10 tons manure plowed under | 10 tons manure plowed under | 1.26 | 2.43 | 9.87 | 1.45 | 11.28 | 2.43 | 4.21 | 32.93 | 30.00 | 2.93 |
| 16 | 300 lbs. 2–12–6 in bottom of furrow | 300 lbs. 2–12–6 in bottom of furrow | −0.34 | 1.01 | 2.88 | 0.25 | 4.03 | 0.52 | 1.03 | 9.38 | 8.40 | 0.98 |
| 18 | 350 lbs. 0–20–0 and 200 lbs. 0–0–50 broadcast, disced in, and plowed under; 125 lbs. 2–12–6 in the row | None | 0.13 | 2.43 | 6.55 | 0.60 | 2.21 | 0.26 | 2.27 | 14.45 | 10.25 | 4.20 |
| 19 | 350 lbs. 0–20–0, 200 lbs. 0–0–50, and 500 lbs. $CaCN_2$ broadcast, disced in, and plowed under; 125 lbs. 2–12–6 in the row | None | −1.55 | 2.82 | 8.82 | 1.05 | 5.45 | 0.88 | 3.25 | 20.72 | 19.13 | 1.59 |

*Values based on increases given in Tables 1 and 4.

Manure at \$1.50 per ton
2–12–6 at \$27.94 per ton
$(NH_4)_2SO_4$ at \$37.78 per ton
4–24–12 at \$51.00 per ton

0–20–0 at \$23.40 per ton
0–0–50 at \$44.10 per ton
$CaCN_2$ at \$35.50 per ton

Corn at \$0.61 per bu.
Wheat at \$0.75 per bu.
Barley at \$0.54 per bu.

Clover hay at \$8.95 per ton
Straw at \$3.00 per ton
Stover at \$3.00 per ton

†Fertilizer costs based on average retail price for duration of period used in the experiment.
Grain prices are 10-year average prices furnished by government agricultural statitician's office, Lansing, Michigan. Straw, stover, and manure prices estimated.

failed so there would be no hay crop, it was reseeded in the spring in order that there would be a green manuring crop to plow under for corn each year.

### RESULTS WITH BARLEY

Barley yields varied considerably from year to year and, on the whole, are low, as the soil is not well adapted to barley production. Adverse weather conditions which delayed seeding and deficiency of moisture during the growth period are primarily responsible for the annual variations in yield. Differences in increases in yields resulting from fertilization are not appreciable except in those from the three plots receiving manure and from plots 12, 18, and 19, the latter two of which received a heavy application of fertilizer for corn (Table 4). It is noteworthy that the 10-ton manure applications plowed under were more effective than the 5-ton top-dressing. This was to be expected, as these two plots received four times as much manure during the rotation period as did plot 7 which received the top-dressing, and the growth of the barley was dependent on the residual fertility in the soil as it was not fertilized directly. No reason is evident for the above-average increase from plot 12.

### RESULTS WITH WHEAT

As the wheat crop was fertilized directly, more response to applied fertilizer was to be expected than in the case of barley and clover. Yield increases varied from 4.14 to 17.74 bushels. Again, the largest increases were obtained from the plots treated with manure. Plowing under 10 tons of manure reinforced with 300 pounds of 0–12–0 gave the largest yield increase, followed by the manure application without the 0–12–0, and the 5-ton top-dressing with 300 pounds of 2–12–6 drilled with the seed which gave almost identical increases. Of the treatments consisting of commercial fertilizer only, those in which all or a part of the fertilizer was drilled with the seed were the most effective. Of the non-localized fertilizer applications, the placing of the fertilizer deep in the soil by plowing it under or by drilling it deep were not so effective as keeping it near the seed by broadcasting and working it into the surface soil. The value of nitrogen in the early spring is evidenced by the large increase from plot 6, which received the top-dressing of sulfate of ammonia. As might be expected, the spring application of available nitrogen was detrimental rather than beneficial to the clover seeded in the wheat.

### RESULTS WITH CORN

It is noteworthy that all fertilizer applications increased the yield of corn grain with the exception of that in which the fertilizer was placed at the bottom of the furrow (Fig. 1). In the case of 6 of the 11 treatments, the increase was less than 3 bushels to the acre. Furthermore, quite frequently a fertilized plot yielded less than the adjoining untreated plot for a given year. A decrease in yield (−0.55 bushel) occurred when the fertilizer was placed in the bottom of the furrow, a method which might be expected to prove beneficial since the

Fig. 1.—Effect of fertilizer vs. no fertilizer for corn in 1939. Left, check; right, 300 pounds of 2–12–6 below seed in row. This condition is typical for these treatments in early summer. Yield, left, 30.82 bushels corn and 2,986 pounds stover per acre; right, 29.15 bushels corn and 3,547 pounds stover per acre. These same treatments in 1938 produced the following results: Left, 52.67 bushels corn and 3,920 pounds stover; right 57.04 bushels corn and 5,410 pounds stover per acre.

nutrients were in moist soil a larger proportion of the time than were those placed nearer the soil surface. The largest yield increase (6.80 bushels) was obtained from the plot which received 300 pounds of fertilizer for wheat with 5 tons of manure applied as a spring top-dressing but no fertilizer for corn. A 10-ton application of manure plowed under gave the small increase of 2.07 bushels in corn grain, and supplementing the manure with 300 pounds of 0–12–0 resulted in only 1.44 bushels further increase. Side dressing with a cultivator proved a very unsatisfactory method of applying fertilizer to corn.

Applications of manure and of fertilizer placed near the seed stimulated the early growth of the corn and materially increased the yields of stover (Fig. 2). Methods of placement which put the nutrients near the seed were especially effective in increasing early growth and plowing under manure resulted in the greatest increases in stover

Fig. 2.—Effect of row fertilization vs. broadcast fertilization for corn in 1939. Left, 300 pounds of 2–12–6 in the row; right, 300 pounds of 2–12–6 broadcast. This is typical of these treatments in early summer. Yield, left, 27.88 bushels of corn and 3,263 pounds stover; right, 35.23 bushels corn and 3,249 pounds stover. These same treatments in 1938 produced the following results: Left, 59.62 bushels corn and 5,061 pounds stover; right, 60.86 bushels corn and 4,484 pounds stover.

yields. Of especial interest is the fact that the smallest increase in yield of stover accompanied the greatest increase in yield of grain. Surprisingly, however, the next to the smallest increase in stover was obtained from the plot that gave a very small (2.10 bushels) increase in grain. Evidently there was no consistent correlation between stover yields and grain yields.

Because of the lack of correlation between early growth and grain yield and between yields of stover and grain, some additional fertilizer treatments were added. It was thought that omission of the nitrogen from the fertilizer might result in less early growth of the plants and still increase the yield. The average results from 300 pounds of fertilizer with and without nitrogen drilled in the row for corn and wheat are given in Table 3. The data show no appreciable difference in yield of corn grain or stover as a result of omitting the nitrogen.

Another thought was that a small amount of fertilizer might stimulate the production of larger plants which did not produce a correspondingly large amount of grain because of an insufficient supply of nutrients in the latter part of the growing season. Accordingly, a fertilizer application consisting of 500 pounds of calcium cyanamide, 350 pounds of 0–20–0, and 200 pounds of 0–0–50 was broadcast and plowed under, and 125 pounds of 2–12–6 were drilled with the corn seed. An adjoining plot received the same treatment with the omission of the calcium cyanamide. No fertilizer was applied for wheat on these plots.

The results (Table 4) show a decrease of 2.54 bushels of corn for the plot receiving the complete treatment and no appreciable increase for the treatment without the cyanamide. Stover yields were increased decidedly in each case. Yields of other crops in the rotation were increased, especially by the treatment including 500 pounds of cyanamide and particularly in the case of barley which followed the corn. The plot which received the cyanamide gave a wheat yield increase 2.46 times that from the plot which received the phosphate and potash without the extra nitrogen. The yield increase from the latter plot was no greater than might have been expected from the 125 pounds of 2–12–6 drilled with the seed.

Inasmuch as heavy applications of plant nutrients did not materially increase the yield of corn, a further study of the available data was made in an effort to determine why corn does not respond more favorably to fertilizer on this soil.

It is to be expected that quantity and distribution of rainfall would have a marked influence on the effect of fertilizer on grain yields. To study the part played by this factor in the present experiment, the results for the period of 1931 to 1934, inclusive, including two seasons of limited summer rainfall, are compared to those for a period of more satisfactory precipitation (1935 to 1941, inclusive) in Table 5. The rainfall data are presented in Table 6. The period included in the experiment was preceded by a year (1930) of very low rainfall which would tend to deplete the soil moisture supply. The critical period for corn in Michigan, so far as moisture supply is concerned, comes in the latter half of July and in August. This period was very dry in 1931.

TABLE 3.—*Effect of 0–12–6 and 2–12–6 fertilizers on the yield of corn, barley, wheat, and clover.*

| Treatment for both corn and wheat | Corn, 8-year av. | | | | Barley, 7 -ear av. | | | | Wheat, 7-year av. | | | | Clover hay, 6-year av.* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Grain, bu. | | Stover, lbs. | | Grain, bu. | | Straw, lbs. | | Grain, bu. | | Straw, lbs. | | | |
| | Acre yield | Increase over check | Acre yield | Increase over check | Acre yield | Increase over check | Acre yield | Increase over check | Acre yield | Increase over check | Acre yield | Increase over check | Acre yield, lbs. | Increase over check, lbs. |
| 300 lbs. 0–12–6 drilled in row with corn........ 300 lbs. 0–12–6 drilled with wheat | 37.30 | 1.77 | 4,054 | 789 | 21.51 | 2.72 | 1,129 | 16 | 28.20 | 4.83 | 2,258 | 247 | 1,709 | 236 |
| 300 lbs. 2–12–6 drilled in row with corn........ 300 lbs. 2–12–6 drilled with wheat | 36.53 | 1.00 | 4,047 | 782 | 23.93 | 5.14 | 1,194 | 81 | 28.23 | 4.86 | 2,278 | 267 | 1,969 | 496 |

*Clover seedings failed two years. The averages given here are for four harvests divided by six.

TABLE 4.—*Effect of heavy fertilizer applications, including calcium cyanamide, on the yield of corn, barley, wheat, and clover.*

| Plot No. | Treatment* | Corn, 6-year av. | | | | Barley, 5-year av. | | | | Wheat, 4-year av. | | | | Clover hay; 3-year av.† | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Grain, bu. | | Stover, lbs. | | Grain, bu. | | Straw, lbs. | | Grain, bu. | | Straw, lbs. | | | |
| | | Acre yield | Increase over check | Acre yield | Increase over check | Acre yield | Increase over check | Acre yield | Increase over check | Acre yield | Increase over check | Acre yield | Increase over check | Acre yield, lbs. | Increase over check, lbs. |
| 18 | 350 lbs. 0–20–0 and 200 lbs. 0–0–50 broadcast, disced in, and plowed under + 125 lbs. 2–12–6 in the row | 35.97 | 0.21 | 4,909 | 1,617 | 30.25 | 12.13 | 1,539 | 402 | 27.67 | 2.95 | 2,139 | 174 | 2,171 | 507 |
| 19 | 350 lbs. 0–20–0, 200 lbs. 0–0–50, and 500 lbs. $CaCN_2$ broadcast, disced in, and plowed under + 125 lbs. 2–12–6 in the row | 33.15 | −2.54 | 5,134 | 1,878 | 33.56 | 16.33 | 1,827 | 700 | 31.48 | 7.26 | 2,504 | 586 | 2,212 | 726 |

*Fertilizer was applied for corn only.
†There was no clover in 1940 due to failure of seedings in 1939. The averages given here are for two harvests divided by three.

In 1934 there was very little rain in July after July 6, and with the exception of the month of April, the critical period was preceded by several months of below-normal precipitation.

During the latter period (1935 to 1941, inclusive), 1936 was the most unfavorable year. The heaviest rainfall of that season was fairly well disbributed through the month of September which was too late to do the corn much good. While the July precipitation for 1937 to 1940, inclusive, was below normal, it was, in most cases, preceded and followed by months of sufficient rainfall.

During the period of adverse weather only 4 of the 11 treatments gave positive increases in yield, while during the favorable seasons all but one treatment gave positive increases. In seasons of low precipitation placing the fertilizer deep in the soil by plowing it under, and by putting it in the bottom of the furrow resulted in decreased yields, although these are methods of application which might be expected to prove beneficial in dry seasons. Placing the fertilizer under the furrow slice also gave a negative yield increase during the period of more favorable seasons. It is interesting to note that the treatment which gave the highest average increase during the period of more favorable rainfall involved applying no fertilizer for corn directly. The wheat was fertilized and also top-dressed with 5 tons of manure. This procedure evidently supplied sufficient nutrients for the corn, but did not stimulate excessive early growth. This was also the second best treatment in the more unfavorable period. Placing fertilizer deep with the planter before drilling the seed gave comparatively good results in both wet and dry seasons but required additional labor.

The year 1934 was a very poor corn year, while 1937 was an exceptionally favorable season. A study of the data for the latter year shows that corn will respond very satisfactory to fertilizer applications when climatic conditions throughout the growing season are favorable for the crop. Drilling the fertilizer near the seed is a very satisfactory method of application under such conditions as is also putting all the fertilizer on the wheat crop.

Although there is no consistent correlation between yields of stover and grain, there is reason for thinking that treatments which result in a large growth of stalk, particularly in the early summer, are not conducive to large yields of grain unless the latter part of the season is especially favorable. Some of the factors which contribute to these results are discussed below.

A record was kept of the number of suckers and number of ears produced on the two center rows of corn on each plot for a period of 8 years. These sucker counts are presented in Table 7, together with the average yields of grain for that period. The percentage of plants producing ears, the yields, and the weight of 100 ears of corn for the adverse year of 1934 and the favorable year of 1937 are also given. It is noticeable that there is a great difference in the number of suckers produced on each plot from year to year.

The exceptionally large number of suckers produced on all plots during the unfavorable year of 1934 was undoubtedly due to the favorable growth conditions during the early part of the season.

TABLE 5.—*Differences in average yields of corn between the periods of 1931–34 and 1935–41 and for 1934 and 1937 as affected by seasonal conditions.*

| Plot No. | Treatment | | Corn, yields bu. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1931 to 1934, inclusive | | 1935 to 1941, inclusive | | 1934 | | 1937 | |
| | For corn | For wheat | Acre yield | Increase over check* | Acre yield | Increase over check | Acre yield | Increase over check | Acre yield | Increase over check |
| 1 | 300 lbs. 2–12–6 drilled deep, solid | 300 lbs. 2–12–6 drilled deep, solid | 28.41 | −1.59 | 44.02 | 5.52 | 8.77 | −4.03 | 62.87 | 9.12 |
| 3 | 300 lbs. 2–12–6 broadcast and plowed under | 300 lbs. 2–12–6 broadcast and plowed under | 28.77 | −0.73 | 44.84 | 3.64 | 12.14 | −0.66 | 61.00 | 7.25 |
| 4 | 200 lbs. 2–12–6 drilled deep, solid; 100 lbs. 2–12–6 in row | 200 lbs. 2–12–6 drilled deep, solid; 100 lbs. 2–12–6 with seed | 29.51 | 0.01 | 48.86 | 5.56 | 10.05 | −2.95 | 70.08 | 16.43 |
| 6 | 300 lbs. 2–12–6 deep with planter before drilling seed | 300 lbs. 2–12–6 with seed; top-dressed in spring with 60 lbs. $(NH_4)_2SO_4$ | 35.04 | 4.79 | 50.53 | 6.03 | 16.50 | 1.80 | 70.41 | 17.81 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 7 | None | 300 lbs. 2–12–6 with seed; top-dressed in spring with 5 tons manure | 35.26 | 4.26 | 51.98 | 8.28 | 21.93 | 6.18 | 64.70 | 13.20 |
| 9 | 300 lbs. 2–12–6 in row | 300 lbs. 2–12–6 drilled with seed | 31.14 | −2.06 | 46.54 | 4.84 | 15.31 | −1.94 | 69.52 | 17.82 |
| 10 | 300 lbs. 2–12–6 broadcast and worked in | 300 lbs. 2–12–6 broadcast and worked in | 34.85 | 1.10 | 47.17 | 6.42 | 19.87 | 2.12 | 63.06 | 10.06 |
| 12 | 300 lbs. 2–12–6 side dressed with cultivator | 150 lbs. 4–24–12 drilled with seed | 31.31 | −1.14 | 41.39 | 1.99 | 15.01 | −3.89 | 61.72 | 5.92 |
| 13 | 10 tons manure and 300 lbs. 0–12–0 plowed under | 10 tons manure and 300 lbs. 0–12–0 plowed under | 29.64 | −1.66 | 45.63 | 6.63 | 10.26 | −9.14 | 65.62 | 9.12 |
| 15 | 10 tons manure plowed under | 10 tons manure plowed under | 31.04 | −0.26 | 42.09 | 3.39 | 11.89 | −7.61 | 64.27 | 8.97 |
| 16 | 300 lbs. 2–12–6 in bottom of furrow | 300 lbs. 2–12–6 in bottom of furrow | 31.71 | −0.39 | 38.22 | −0.63 | 10.04 | −9.06 | 57.63 | 5.43 |

*The minus signs show that the treated plots yielded less than the check.

Observations during this study indicated that the quantity of available nutrients immediately surrounding the young plants has a greater influence on sucker production than does the general fertility level of the soil. The factors of weather and fertility which induce sucker production also tend to promote a heavy growth of foliage, which in case of a limited moisture supply later in the season may result in an increased barrenness of stalks and a general decrease in yield of grain.

TABLE 6.—*Precipitation in inches during the growing periods covering part of the duration of the experiment reported**.

| Year | Apr. | May | June | July | Aug. | Sept. | Total | Annual |
|---|---|---|---|---|---|---|---|---|
| 1930...... | 1.97 | 3.36 | 2.79 | 0.50 | 0.18 | 1.42 | 10.22 | 18.50 |
| 1931...... | 1.87 | 3.71 | 3.73 | 0.92 | 1.70 | 3.33 | 15.26 | 28.63 |
| 1932...... | 2.18 | 5.03 | 1.24 | 3.44 | 3.71 | 3.04 | 18.64 | 34.22 |
| 1933...... | 3.35 | 3.95 | 2.56 | 1.43 | 2.14 | 5.37 | 18.80 | 31.66 |
| 1934...... | 2.68 | 1.33 | 1.67 | 2.14 | 1.51 | 2.21 | 11.54 | 21.00 |
| 1935...... | 1.60 | 3.88 | 4.95 | 2.60 | 2.69 | 2.49 | 18.21 | 31.28 |
| 1936...... | 3.37 | 0.78 | 2.98 | 1.22 | 2.42 | 7.76 | 18.53 | 27.65 |
| 1937...... | 6.33 | 3.43 | 6.77 | 1.64 | 4.42 | 1.28 | 23.87 | 33.60 |
| 1938...... | 1.42 | 5.73 | 2.89 | 1.50 | 4.24 | 1.64 | 17.42 | 32.39 |
| 1939...... | 4.21 | 2.07 | 3.77 | 1.60 | 1.97 | 1.41 | 15.03 | 27.18 |
| 1940...... | 1.42 | 4.66 | 5.70 | 1.84 | 9.21 | 1.42 | 24.25 | 37.84 |
| Normal.... | 2.58 | 3.42 | 3.51 | 3.10 | 2.82 | 2.91 | 18.34 | 31.43 |

*These figures obtained from the U. S. Weather Bureau Station at East Lansing, Mich., where the experiment was conducted.

This statement is partly borne out by observations of increased barrenness of plants on fertilized plots in some years and partly by the figures in Table 7. These figures show a much larger number of suckers from given treatments in 1934 than in 1937. The yields of stover from given treatments for the two years are fairly comparable, although they, as well as the number of suckers, are larger on fertilized plots than on check plots. The yield of grain and percentage of ear-bearing plants, however, were low for 1934, with a tendency for yields to be lower on fertilized plots than on check plots. While the average results for 8 years show no consistent relationship between yield of grain and number of suckers produced, there is a tendency in given seasons toward a direct relationship between number of suckers and yield of stover and an inverse relationship between number of suckers and yield of grain. The development of normally dormant buds on the ear shanks, resulting in two or more ears on the same shank, is also stimulated by available nutrient elements near the plants. These multiple ears (Fig. 3) produce practically no kernels.

The yield of grain is affected by both the size of ears and the percentage of ear-bearing plants, either or both of which may be affected by fertilizer treatments. By inducing the development of large leafy plants larger ears will be produced in favorable years, and, on the other hand, smaller ears in unfavorable years because of the increased demand for soil moisture. Fertilizers may influence the percentage of

ear-bearing plants by bringing them to the ear-setting stage or to the pollination period at a time when conditions are unfavorable for these processes.

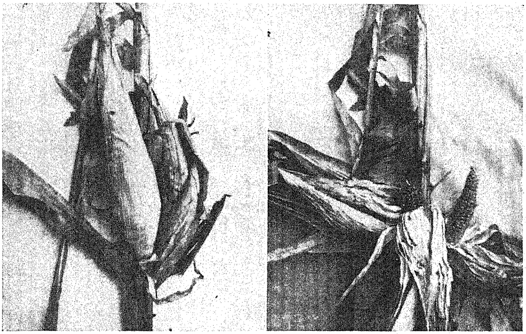

FIG. 3.—Multiple ears are often prevalent where rapid early growth takes place followed by hot dry weather in midsummer. This condition is usually associated with favorable weather conditions in the early part of the season and an abundance of readily available plant food, where manure is plowed under or commercial fertilizer placed in the row. Left, two rudimentary ears on the same shank. Right, same with husks stripped back. Note the absence of kernels.

## SUMMARY AND CONCLUSIONS

A study was made of the effect on crop yields of applying 2–12–6 fertilizer by different methods to corn and wheat in a rotation of corn, barley, wheat, and clover grown on Hillsdale sandy loam soil. Some treatments also included manure, heavy applications of fertilizer plowed under for corn, and 0–12–6 fertilizer. Each crop was grown every year.

The increases in yield resulting from fertilization are probably greater than they would have been had the experiment been placed on a different field each year as the soil of the untreated or check plots became somewhat less productive as the years passed.

In an effort to explain the response of corn to different soil treatments, observations and records were made of the effects of seasonal conditions and of a combination of fertilizer treatment and seasonal conditions on crop growth and yield. Counts were made of the number of corn suckers produced per plot for a number of years and of the number of good and poor ears. Average weights of ears were determined and a relationship worked out between soil treatments, weather conditions, yields, size of ears, and percentage of ear-bearing stalks.

Although no fertilizer was applied directly for barley and clover, these crops showed noticeable responses to the residues of fertilizer

TABLE 7.—*Effect of fertilizer treatments and season on sucker production, yield of corn, percentage of ear-bearing plants, and weight per ear.*

| Plot No. | Treatment for corn | Number of suckers per 180 feet of row | | | | | | | | | | 1934 crop | | | | | 1937 crop | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1934 | 1935 | 1936 | 1937 | 1938 | 1939 | 1940 | 1941 | Av. | Av. yield, 1934–41, bu. | No. of suckers in 180 ft. of row | Acre yield: Stover, lbs. | Acre yield: Grain, bu. | Corn per 100 ears, lbs. | Ear-bearing plants, %* | No. of suckers in 180 ft. of row | Acre yield: Stover, lbs. | Acre yield: Grain, bu. | Corn per 100 ears, lbs. | Ear-bearing plants, %* |
| 1 | 300 lbs. 2–12–6 drilled deep, solid | 55 | 2 | 21 | 11 | 8 | 3 | 6 | 6 | 14 | 39.61 | 55 | 3,675 | 8.77 | 13.25 | 48.20 | 11 | 3,917 | 62.87 | 38.57 | 107.84 |
| 2 | Check | 29 | 0 | 16 | 3 | 3 | 0 | 0 | 2 | 6⅝ | 36.04 | 29 | 3,136 | 12.64 | 15.61 | 57.34 | 3 | 3,243 | 53.69 | 33.55 | 103.84 |
| 3 | 300 lbs. 2–12–6 broadcast and plowed under | 17 | 0 | 10 | 1 | 8 | 2 | 8 | 2 | 6 | 40.75 | 17 | 3,682 | 12.14 | 12.94 | 62.91 | 1 | 3,886 | 61.00 | 39.34 | 100.00 |
| 4 | 200 lbs. 2–12–6 drilled deep solid; 100 lbs. 2–12–6 in row | 34 | 8 | 25 | 15 | 10 | 6 | 1 | 16 | 14⅜ | 44.00 | 34 | 3,796 | 10.05 | 12.41 | 55.03 | 15 | 4,301 | 70.08 | 43.00 | 103.77 |
| 5 | Check | 21 | 2 | 7 | 2 | 6 | 0 | 0 | 4 | 5¼ | 40.67 | 21 | 3,751 | 13.51 | 13.03 | 67.74 | 2 | 3,284 | 53.29 | 35.26 | 102.00 |
| 6 | 300 lbs. 2–12–6 deep with planter before drilling seed | 74 | 7 | 43 | 37 | 17 | 22 | 2 | 39 | 30⅛ | 46.27 | 74 | 4,660 | 16.50 | 15.91 | 70.95 | 37 | 4,553 | 70.41 | 40.97 | 115.23 |

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | None | 26 | 0 | 14 | 5 | 9 | 0 | 0 | 6 | 7½ | 48.22 | 26 | 4,311 | 21.93 | 18.05 | 85.42 | 5 | 3,775 | 64.70 | 41.20 | 103.92 |
| 8 | Check | 18 | 1 | 10 | 2 | 1 | 2 | 0 | 2 | 4½ | 39.37 | 18 | 3,609 | 16.66 | 17.39 | 66.44 | 2 | 3,257 | 50.83 | 34.54 | 97.38 |
| 9 | 300 lbs. 2–12–6 in row | 60 | 22 | 37 | 38 | 13 | 17 | 0 | 45 | 29 | 42.63 | 60 | 4,391 | 15.31 | 15.82 | 68.06 | 38 | 4,608 | 69.52 | 40.45 | 112.99 |
| 10 | 300 lbs. 2–12–6 broadcast and worked in | 18 | 1 | 19 | 1 | 3 | 1 | 2 | 6 | 6⅜ | 43.75 | 18 | 3,820 | 19.87 | 19.16 | 75.54 | 1 | 3,834 | 63.06 | 40.93 | 104.00 |
| 11 | Check | 7 | 0 | 7 | 1 | 0 | 3 | 0 | 3 | 2⅝ | 37.23 | 7 | 3,277 | 18.17 | 16.43 | 76.19 | 1 | 3,194 | 54.30 | 35.47 | 100.65 |
| 12 | 300 lbs. 2–12–6 side dressed with cultivator | 37 | 2 | 19 | 11 | 10 | 12 | 18 | 11 | 15 | 38.09 | 37 | 4,135 | 15.01 | 13.69 | 75.00 | 11 | 4,408 | 61.72 | 39.80 | 100.64 |
| 13 | 10 tons manure and 300 lbs. 0–12–0 plowed under | 41 | 3 | 40 | 11 | 28 | 9 | 9 | 24 | 20⅝ | 41.20 | 41 | 5,085 | 10.26 | 12.83 | 59.56 | 11 | 5,289 | 65.62 | 42.86 | 99.36 |
| 14 | Check | 33 | 0 | 12 | 5 | 0 | 0 | 1 | 5 | 7 | 36.41 | 33 | 3,606 | 19.57 | 16.65 | 81.51 | 5 | 3,564 | 56.51 | 35.76 | 101.91 |
| 15 | 10 tons manure plowed under | 26 | 3 | 47 | 5 | 27 | 5 | 3 | 16 | 16½ | 38.31 | 26 | 5,130 | 11.89 | 15.64 | 54.61 | 5 | 5,037 | 64.27 | 41.18 | 98.75 |
| 16 | 300 lbs. 2–12–6 in bottom of furrow | 40 | 0 | 18 | 6 | 3 | 4 | 4 | 8 | 10⅜ | 34.69 | 40 | 4,923 | 10.04 | 13.03 | 52.35 | 6 | 4,124 | 57.63 | 37.89 | 100.65 |
| 17 | Check | 23 | 0 | 10 | 1 | 3 | 2 | 0 | 9 | 6 | 36.54 | 23 | 3,917 | 18.37 | 16.91 | 76.39 | 1 | 2,945 | 47.66 | 32.38 | 102.05 |

*Ratio of number of ears to number of plants per plot. Some plants were barren while others bore more than one ear.

applied to other crops in the rotation. Residues from manure applications produced the greatest increases in clover. Barley yields were materially increased by residues of manure and of heavy applications of commercial fertilizer. Seasonal conditions also greatly influenced the growth of clover and barley.

Manure plowed under resulted in the largest yields of wheat, followed by commercial fertilizer drilled with the seed supplemented with a spring topdressing of manure. Commercial fertilizer drilled with the wheat seed gave better results than that applied broadcast and worked into the soil or that plowed under. Superphosphate used as a reinforcement to manure gave some, but not outstanding, increase in wheat yields.

There was a very close relationship between yields of grain and straw in the case of wheat and barley, but no such relationship existed between yields of corn grain and stover. The largest increases in stover yields resulted from applications of manure and from heavy applications of commercial fertilizer, especially fertilizer containing excessive amounts of nitrogen. Moderate applications of fertilizer produced larger yield increases of stover when placed in or near the row than when broadcast or plowed under. The proportion of grain to stover was greatest in corn grown on plots receiving broadcast applications of fertilizer and on plots well fertilized for wheat but receiving no fertilizer for corn.

The largest average yield of corn grain was obtained from the plot receiving 300 pounds of 2–12–6 fertilizer for wheat and a spring topdressing of 5 tons of manure, with no fertilizer applied for corn. In favorable seasons all fertilizer treatments resulted in increased corn yields, but in unfavorable seasons fertilizer applications were of little and frequently of negative value. Considering the average increases for the 11-year period, the results show little benefit from fertilizer applied directly for corn.

Considering the rotation as a whole, there was a net financial gain from all fertilizer treatments. The frequent failure of corn to respond satisfactorily to fertilizer materially reduced the returns for the rotation.

The tendency for fertilizer to increase the early growth of corn and to stimulate the production of suckers resulted, in dry years, in smaller ears and a higher percentage of barren stalks. These effects appear to account for the lower yields of grain and higher stover yields on the fertilized plots than on those receiving no fertilizer in unfavorable seasons. From the results it appears that the best way to increase corn yields on this soil type is to fertilize other crops in the rotation rather heavily, making use of green manures or animal manure, and to let the corn draw on the stored fertility. A direct correlation was found between yield in bushels, on the one hand, and size of ear and percentage of ear-bearing plants, or a combination of these two factors, on the other.

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# RESPONSE OF SOYBEANS TO EXPERIMENTAL DEFOLIATION[1]

R. M. Gibson, R. L. Lovvorn, and Ben W. Smith[2]

THE increasing livestock industry in the southeastern states has necessitated a cheap source of forage. Supplementary pastures are recognized by most livestock men as essential for the economical production of beef or dairy products. This is especially true in many of the well-drained, sandy soils where permanent pastures are not adequate. The acreage of soybeans utilized as a grazing crop has increased recently in North Carolina, Biloxi being the variety most often used for this purpose. The authors are not aware of any controlled experiments in which the management of the soybean as a grazing crop has been investigated. Cattle are usually turned on to the crop and allowed to consume most of the foliage within a few days. They are then removed and the crop is allowed to produce new leaves. Information is needed on the varietal response to the frequency and degree of defoliation, and it was the object of the work reported in this paper to measure such response in the Biloxi and Tokyo varieties.

Most defoliation studies on perennials have been concerned with the maintenance of organic root reserves adequate for initiating new growth the following growing season. Such reserves are not so essential in annuals. A photosynthetic area must be maintained, however, that will permit recovery within the single growing season.

Eldredge (2),[3] Dungan (1), Hume and Franzke (3), and Li and Liu (5) have shown that grain yields of corn and *Andropogon sorghum* vary inversely with the degree of defoliation and that the reduction becomes progressively less as the plants approach maturity. Leukel, *et al.* (4) reported that cutting Sudan grass four times after it had reached a height suitable for grazing prevented new top growth. In the case of the soybean, information is needed on the effect of defoliation on both the recovery of leaves and the ultimate seed yield.

## MATERIALS AND METHODS

Biloxi and Tokyo soybean varieties were grown on a Congaree sandy loam at Raleigh, N. C., during the summer of 1940 for the purpose of studying the effect of defoliation on leaf, stem, and seed yield. All of the combinations of four degrees and three frequencies of defoliation were studied. The treatments were as follows:

1. The light defoliation treatment consisted in the removal of all but six

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[3]Figures in parenthesis refer to "Literature Cited", p. 778.

leaves per plant at 10-, 20-, or 30-day intervals throughout the growing season, with the terminal bud remaining on the plant.

2. The medium defoliation treatment consisted in the removal of all but three leaves per plant at 10-, 20-, or 30-day intervals, with the terminal bud remaining on the plant.

3. The medium-bud removed defoliation treatment was the same as the medium defoliation, except that the terminal bud was also removed by breaking out the top of the plant at the time of leaf removal.

4. The severe or heavy defoliation treatment consisted in the complete defoliation of each plant at the specified frequency intervals.

5. The check was not defoliated until the end of the growing season.

A split-plot experimental design was used in which the two varieties were treated as whole plots and the 13 defoliation treatments as subplots. Each subplot consisted of one row 18 feet in length. Ten replications were used.

Treatments at the 10-, 20-, and 30-day frequencies on both varieties were begun on July 2, 5, and 8, respectively, and were continued through September 3, 5, and 7, respectively. Leaves were removed individually by grasping the base of the leaflets between the thumb and forefinger and snapping them off at the point where they joined the petiole. It has been observed that grazing animals remove very little, if any, of the petiole.

Analysis of variance, as described by Snedecor (6), was used on all of the data. The means for each degree of defoliation at each frequency are given in the tables. The frequency means were computed by combining the different degrees of defoliation. Likewise, the means for the degrees of defoliation were computed by combining the different frequencies of defoliation. Odds of 99:1 were used throughout in determining levels of significance.

## EXPERIMENTAL RESULTS

### TOTAL WEIGHT OF LEAVES PRODUCED

The mean yields of leaves for the various treatment combinations are shown in Table 1. Yields from the check plot were not included because of the shedding of the leaves. These data show that the total leaf yield of the two varieties did not differ significantly and that

TABLE 1.—*Total dry weight of leaves in grams.*

| Degree of defoliation | Biloxi | | | | Tokyo | | | |
|---|---|---|---|---|---|---|---|---|
| | Frequency in days | | | Degree mean | Frequency in days | | | Degree mean |
| | 10 | 20 | 30 | | 10 | 20 | 30 | |
| Severe | 427 | 552 | 938 | 639 | 470 | 724 | 902 | 699 |
| Medium bud removed | 782 | 1,056 | 986 | 941 | 810 | 876 | 943 | 876 |
| Medium | 828 | 1,089 | 1,039 | 985 | 918 | 973 | 954 | 948 |
| Light | 855 | 817 | 803 | 825 | 894 | 843 | 696 | 811 |
| Frequency mean | 723 | 878 | 942 | 848 | 773 | 854 | 874 | 834 |

The least significant difference:
Between frequency means . . . 73
Between degree means . . . 84
Between degrees within any frequency . . . 146

frequency of defoliation affected both varieties in a similar manner. The means of the 10-day defoliation treatments were significantly lower than the corresponding 20- and 30-day means. Although the 30-day value is numerically larger than the 20, the difference is not significant.

The general effect of the degree of defoliation is also similar on both varieties. The medium intensity resulted in significantly higher leaf productivity than either the light or severe treatments. Complete defoliation severely reduced the weight of leaves produced. The removal of the terminal bud effected a slight but non-significant reduction in the leaf yield of each variety.

The analysis of the data shows a highly significant interaction between the degree and frequency of defoliation. This means that the response of the plants to the various degrees of defoliation was different as the recovery interval varied. Severely defoliated plants produced maximum growth with a 30-day recovery period, while light defoliation permitted most leaf growth when plants were defoliated every 10 days. The medium degree of defoliation was most efficient when practiced every 20 days, although the differences between the 20- and 30-day intervals are not significant.

Considering the degree of defoliation at a particular frequency, the yield of leaves is greatest, with one exception, with the medium defoliation treatment. Light defoliation at 10-day intervals resulted in a slight but non-significant increase in the productivity of Biloxi plants. Light defoliation at 10- or 20-day intervals resulted in a greater weight of leaves than was produced by plants severely defoliated, but the reverse was true of the 30-day frequency.

The Tokyo variety was less affected by variation of the leaf area than the Biloxi. This is indicated by the larger number of treatment means which do not differ significantly.

## SEASONAL PRODUCTIVITY

The seasonal distribution of the yield is equally as important for grazing management as the total weight of leaves produced. Seasonal data for the 10-, 20-, and 30-day frequencies are presented in Figs. 1, 2, and 3, respectively. As can be seen from these figures, the seasonal decline was greatest in the 10- and least rapid in the 30-day frequency. Medium or light defoliation every 10 days resulted in a fairly uniform Biloxi yield, but a definite peak was reached by the Tokyo on August 24.

The weight of leaves removed at the first and last harvest were approximately the same from the light and medium defoliations every 20 days; the last harvests were larger in case of the 30-day interval with the same degree of defoliation.

## RECOVERY GROWTH

Since the weights of leaves removed at the initial harvest were not affected by the treatments, they do not give an indication of the plant response to defoliation. The growth which occurred following the initial treatments is designated as "recovery growth". Differences in

recovery growth made by Biloxi and Tokyo were not statistically significant as can be seen from the data in Table 2. In the case of the Biloxi, the frequency of defoliation affected the amount of recovery growth in the same manner as it affected the total weight of leaves. Yields of Tokyo recovery growth were not significantly different for the three cutting frequencies.

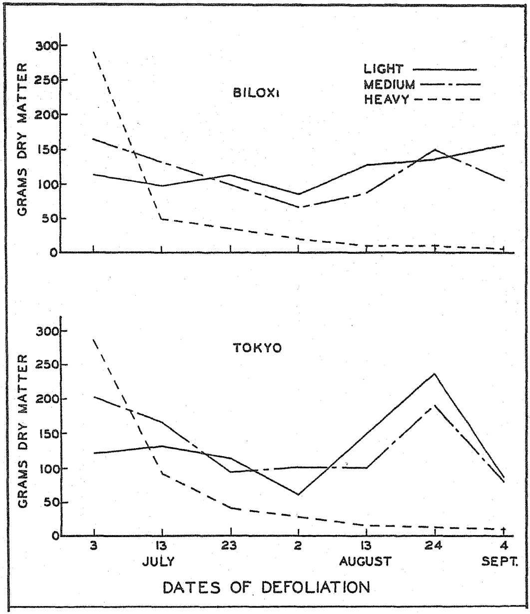


FIG. 1.—Dry weight of soybean leaves when defoliated at 10-day frequency. *Light*, removal of all but six leaves; *medium*, removal of all but three leaves; *heavy*, removal of all leaves throughout growing season.

The severe treatment resulted in significantly less recovery growth than any other degree of defoliation. Differences between light and medium defoliations were not significant, although the actual yields were larger when given the medium treatment. In the case of total yields, the medium defoliation differed significantly from the light.

TABLE 2.—*Dry weight of "recovery growth" of leaves in grams.*

| Degree of defoliation | Biloxi | | | | Tokyo | | | |
|---|---|---|---|---|---|---|---|---|
| | Frequency in days | | | Degree mean | Frequency in days | | | Degree mean |
| | 10 | 20 | 30 | | 10 | 20 | 30 | |
| Severe | 136 | 241 | 547 | 308 | 187 | 373 | 504 | 355 |
| Medium bud removed | 597 | 840 | 730 | 722 | 593 | 644 | 660 | 632 |
| Medium | 661 | 863 | 788 | 771 | 715 | 726 | 704 | 715 |
| Light | 742 | 708 | 650 | 700 | 776 | 706 | 536 | 673 |
| Frequency mean | 534 | 663 | 679 | 625 | 568 | 612 | 601 | 594 |

The least significant difference:
Between frequency means........ 68
Between degree means........ 79
Between degrees within any frequency........ 137

Recovery growth interaction between the degree and frequency of defoliation were also similar to the total weight. Light defoliation with a 30-day frequency resulted in lower recovery growth for both varieties. Medium defoliation at a 20- or 30-day frequency or light defoliation every 10 or 20 days was more favorable to the Biloxi. The severe treatment was not conducive to recovery for either variety.

## WEIGHT OF STEMS AND ROOTS

Table 3 presents the treatment means for the dry weight of stems and roots produced. Biloxi is more productive than Tokyo. Biloxi weights increase significantly as the interval allowed for recovery varied from 10 to 20 and 30 days. The Tokyo means show the same trends, but the difference between the 10- and 20-day means was not greater than expected as a result of random variation.

TABLE 3.—*Dry weight of roots and stems in grams.*

| Degree of defoliation | Biloxi | | | | Tokyo | | | |
|---|---|---|---|---|---|---|---|---|
| | Frequency in days | | | Degree mean | Frequency in days | | | Degree mean |
| | 10 | 20 | 30 | | 10 | 20 | 30 | |
| Severe | 132 | 210 | 782 | 375 | 192 | 424 | 598 | 405 |
| Medium bud removed | 851 | 1,124 | 1,093 | 1,023 | 513 | 575 | 688 | 592 |
| Medium | 993 | 1,155 | 1,329 | 1,159 | 619 | 682 | 846 | 716 |
| Light | 1,264 | 1,293 | 1,641 | 1,399 | 838 | 827 | 1,015 | 893 |
| Frequency mean | 810 | 946 | 1,211 | Check, 2,057 | 540 | 627 | 787 | Check, 1,348 |

The least significant difference:
Between frequency means........ 111
Between degree means........ 128
Between degrees within any frequency........ 222

The severe, medium-bud removed, medium, and light defoliation means are all significantly different from each other. The weight of stems and roots produced increases consistently as the treatments become less severe. A similar trend is shown by the means of the 10-, 20-, and 30-day frequency treatments, but not all differences between means are significant.

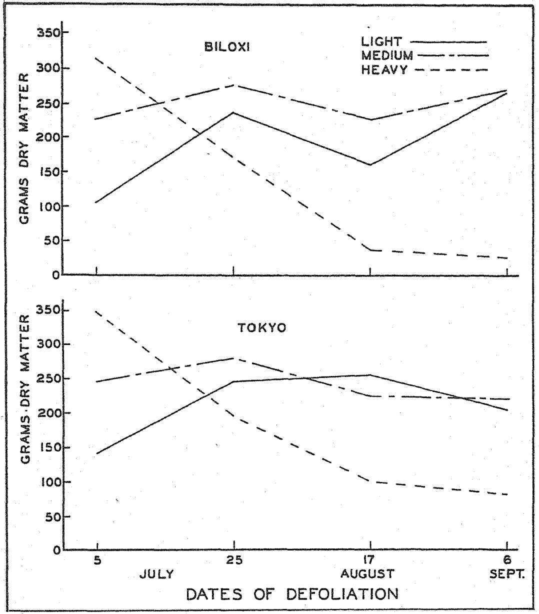


FIG. 2.—Dry weight of soybean leaves when defoliated at 20-day frequency. *Light*, removal of all but six leaves; *medium*, removal of all but three leaves; *heavy*, removal of all leaves throughout growing season.

With two exceptions, the means of each degree of defoliation increase as the time interval between defoliations increases. The 30-day medium-bud removed treatment mean of the Biloxi was slightly less than the corresponding 20-day mean. There was also a slight difference in the 10- and 20-day Tokyo means of lightly defoliated plants.

There is a highly significant interaction between the degree of frequency of defoliation. Except for severely defoliated Tokyo plants, the differences between comparable 10- and 20-day means are slight, being less than the differences between the 20- and 30-day means. The Biloxi shows little increase in productivity when lightly or severely defoliated every 20 days as compared with the 10-day treatment. A marked difference in the weight of stems and roots, however, results from the lengthening of the interval between these treatments from 20 to 30 days.

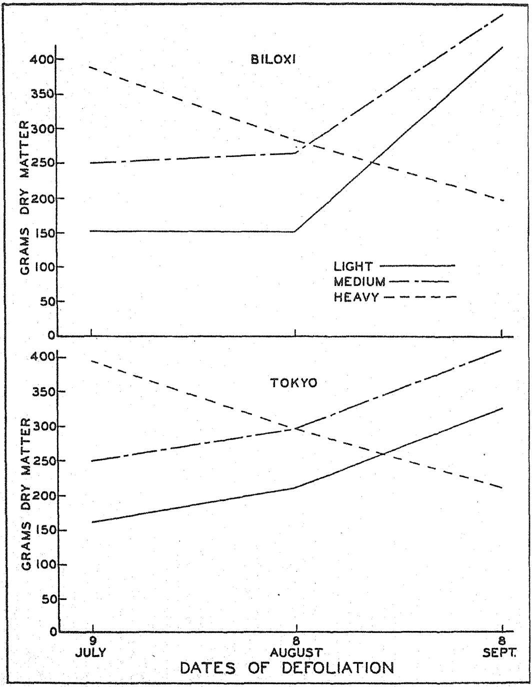


FIG. 3.—Dry weight of soybean leaves when defoliated at 30-day frequency. *Light*, removal of all but six leaves; *medium*, removal of all but three leaves; *heavy*, removal of all leaves throughout growing season.

## WEIGHTS OF BEANS

The weights of beans produced by plants receiving each defoliation treatment are indicated in Table 4. Since data on the severe defoliation treatments were not included in the statistical analysis, the frequency means do not include these data. The Tokyo is superior to the Biloxi as a bean producer. The effect of the frequency of defoliation was similar for the two varieties. The mean of the check is significantly larger than the mean of any other treatment. Differences between the 10- and 20-day means might have been due to random variation, but both were significantly lower than the 30-day mean.

TABLE 4.—*Dry weight of beans in grams.*

| Degree of defoliation | Biloxi: Frequency in days, 10 | Biloxi: Frequency in days, 20 | Biloxi: Frequency in days, 30 | Biloxi: Degree mean | Tokyo: Frequency in days, 10 | Tokyo: Frequency in days, 20 | Tokyo: Frequency in days, 30 | Tokyo: Degree mean |
|---|---|---|---|---|---|---|---|---|
| Severe | 0 | 0 | 2 | 1 | 0 | 30 | 70 | 33 |
| Medium bud removed | 141 | 198 | 218 | 186 | 198 | 248 | 298 | 248 |
| Medium | 182 | 202 | 264 | 216 | 219 | 276 | 328 | 274 |
| Light | 266 | 205 | 292 | 254 | 377 | 378 | 455 | 403 |
| Frequency mean | 196 | 202 | 258 | Check, 380 | 265 | 301 | 360 | Check, 625 |

The least significant difference:
Between frequency means .......... 47
Between degree means .......... 47
Between degrees within any frequency .......... 81

The yields of each variety were highest when plants were lightly defoliated and decreased as the treatments increased in severity. The removal of the terminal bud did not cause a significant reduction in the weight of beans produced. Though the light defoliation mean of the Biloxi is numerically larger than the medium treatment mean, the difference is not greater than that which might be attributed to random variation. The Tokyo means for these treatments are significantly different.

The analysis of the data shows that the major portion of the variation between treatments is due to the differences between the means of the check and the other treatments. Though the variation between degrees and between frequencies is highly significant, the interaction of degree and frequency is not significant. This means that the response of the plants to various frequencies of defoliation was similar as the degree of defoliation varied.

## DISCUSSION

These experiments were conducted only one year and at one location, and the data must be interpreted in view of these limited observations. The results indicate that complete defoliation at any frequency was too severe a treatment for satisfactory growth and

productivity. The medium treatments were more efficient and resulted in significantly higher leaf production than the light or severe defoliations. Unlike many of the perennial grasses, the soybean is stimulated to maximum leaf productivity by the removal of some of the foliage during the period of vegetative growth. This conclusion is supported by the fact that low leaf yields were obtained following light defoliation at intervals of 30 days.

There is a highly significant interaction between the degree and frequency of defoliation. Light defoliation permitted most leaf growth when plants were defoliated every 10 days, while severely defoliated plants produced maximum growth with the 30-day recovery period. The fact that a longer interval between defoliations will partially reduce the ill effects of severe defoliation is of considerable practical importance.

In order that a supplementary pasture may be most useful, it must furnish pasturage when it is most needed. Under actual grazing conditions it is not possible to regulate the degree of defoliation with precision, but the recovery interval can be carefully controlled. The results of these experiments indicate that the soybean plant is physiologically capable of remaining productive in spite of wide variations in defoliation treatment. If these results are applicable to grazing conditions, the intensity of grazing may be varied according to particular needs without serious reductions in the total yield. If the need for forage is great, plants could be rather severely defoliated, provided a longer interval is allowed for recovery. If grazing requirements are not very great at any one time, but extend over a longer period, lighter grazing at more frequent intervals would probably be more efficient.

The seasonal productivity of leaves was affected by both the degree and frequency of defoliation. Yields from severely defoliated plants tended to decrease throughout the season, while yields increased as the season progressed when plants were lightly defoliated. The productivity of moderately defoliated plants was near the same level when 10 or 20 days were permitted for recovery, but increased with a 30-day interval.

Rainfall, temperature, and other ecological factors may be expected to affect the seasonal distribution of leaf yield. These influences are beyond the scope of the present paper. It might be noted, however, that the rainfall for June and July was below normal, while that for August was above normal. The periodicity and quantity of rainfall are listed in Table 5 for the period in which defoliations were made. Mean monthly temperatures were virtually normal for the entire growing season.

Differential responses of varieties of cutting treatments have been found in other species, and it seems reasonable to expect similar results with soybean varieties having different growth habits. The two varieties studied gave the same general types of response to the treatments, but differences in degree of response caused a significant variety-treatment interaction. Tokyo leaf yields were less affected by varying degrees and frequencies of defoliation than those of the Biloxi. Tokyo was also somewhat better adapted to the more frequent de-

foliations. Although the leaf yields from the highest Biloxi treatments were somewhat larger than those from Tokyo, there was no significant difference between the two varieties when all treatments were considered. If Tokyo should produce as well under actual grazing conditions as was indicated by these experimental yields, this variety should probably be seeded more frequently for supplementary pasture. Tokyo stems are somewhat weaker than those of Biloxi, and it is possible that they may be more subject to injury by grazing animals. This may account for the present wider popularity of the Biloxi variety.

TABLE 5.—*Periodicity and quantity of rainfall for periods of defoliation.*

| July | | August | |
|---|---|---|---|
| Date | Rainfall in inches | Date | Rainfall in inches |
| 3 | 0.41 | 5 | 0.07 |
| 4 | 0.15 | 6 | 0.03 |
| 12 | 0.69 | 7 | 0.50 |
| 13 | 0.52 | 8 | 0.01 |
| 19 | 0.16 | 10 | 0.49 |
| 23 | 0.16 | 11 | 0.38 |
| 29 | 0.42 | 13 | 0.03 |
| | | 14 | 4.36 |
| | | 15 | 0.20 |
| | | 16 | 0.08 |
| | | 17 | 0.44 |
| | | 24 | 0.32 |
| | | 25 | 0.02 |
| | | 27 | 0.12 |
| | | 29 | 0.06 |
| Total for month..... | 2.51 | | 7.11 |

For purposes of comparison the total dry weights of leaves (Table 1) have been converted to pounds per acre. The average yield of all treatments for each variety was approximately 1 ton dry weight of leaves per acre. The highest yields, 2,614 and 2,335 per pounds acre, were obtained by medium defoliation of Biloxi and Tokyo plants, respectively, at 20-day intervals. The leaf yields from lightly defoliated plants with a 30-day recovery period were 1,927 and 1,670 pounds per acre for Biloxi and Tokyo, respectively.

Complete defoliation at any frequency studied was too severe to permit effective seed production. The data indicate that the response of the plants to variations in the interval between defoliations was similar for all degrees of defoliation studied. The highest bean yields obtained from treated plants were only 75% of the yield from the undefoliated check. Corresponding treatments caused greater reduction of Tokyo than of Biloxi yields, but the Tokyo produced more beans in all treatments. The bean yields from the treatments resulting in the highest leaf yields were 50 to 70% of the check for Biloxi and 40 to 60% for Tokyo.

## SUMMARY

The reaction of Biloxi and Tokyo soybeans to light, medium, and severe defoliation treatments at 10-, 20-, and 30-day intervals was studied during the 1940 growing season on a Congaree sandy loam soil. The results of this single trial may be briefly summarized as follows:

1. There was a highly significant interaction between the degree and frequency of defoliation.
2. Complete defoliation at any frequency was too severe for satisfactory growth.
3. Medium defoliation treatments resulted in significantly higher leaf yields than the light or severe treatments.
4. The leaf yields of the two varieties did not differ significantly. Tokyo leaf yields were less affected by varying degrees and frequencies of defoliation than those of Biloxi.
5. Weights of stems and roots were inversely related to severity of defoliation treatments.
6. Any degree of defoliation resulted in a decrease in the weight of seed produced. Yields tended to be inversely related to the severity of the defoliation.
7. Defoliation treatments caused greater reductions in seed yields of Tokyo than of Biloxi, but Tokyo produced more beans under all treatments.

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# BORAX AND BORIC ACID FOR CONTROL OF FLIES IN MANURE[1]

A. R. Midgley, W. O. Mueller, and D. E. Dunklee[2]

FARMYARD manure and other rapidly decaying organic matter are the main breeding grounds for houseflies. Houseflies not only annoy both humans and animals but are also carriers of many diseases and parasites, such as typhoid, tuberculosis, dysentery, and intestinal worms (1),[3] as well as of infantile paralysis (7). The polio virus occurs at times in the contents of sewers and open privies, and flies feeding thereon have been found to contain it. Whether polio is usually or seldom thus spread, the possibility constitutes an additional reason for fighting the filthy fly.

The legs of the housefly are thickly covered with hairs and bristles which readily pick up germs whenever they come in contact with infected material. Then, subsequently, when human foods are contacted, they become contaminated with the germs. Many germs live for a long time in the fly's alimentary canal and are either voided in its excrement or extruded in small droplets of regurgitated matter from the mouth.

Farmyard manure and decaying organic matter not only serve as a source of food for flies and their larvae but provide a favorable environment for the development of the eggs. Fly eggs hatch quickly and larvae grow rapidly in horse manure because of its loose nature and its ready decomposition which engenders much heat. Cow manure, relatively wet and compact, is a less favorable medium, but with bedding, and under some conditions without it, the dryer portions promote fly multiplication.

The female fly usually deposits her eggs in the interstices below the surface of the mass of manure. Each female may lay 100 to 150 eggs at a time. These usually hatch the next day, the larvae emerging and feeding upon the decaying organic matter for 5 to 14 days. The larvae then pupate and the young flies emerge 3 to 10 days later. A new generation may arise within the space of 10 days to 2 weeks. The sudden appearance of clouds of flies near actively fermenting manure piles is due to this rapid multiplication and short life cycle.

While fly numbers can be reduced by the use of traps, sprays, and electric screens, a more complete control is needed. To that end their feeding and breeding places should be destroyed or rendered incapable of supporting larval growth. Farm manure, one of the main breeding and feeding mediums, obviously should not be destroyed or rendered unfit for crop fertilization, but should, if possible, be made unfit for the larval growth. An ideal larvaecide should be cheap, readily available, and, if possible, should increase the fertilizing value of the manure. Borax and boric acid seem to meet these requirements.

[1]Contribution from the Agronomy Department, Vermont Agricultural Experiment Station, Burlington, Vt. Received for publication April 2, 1943.

[2]Research Agronomist, former Assistant Research Agronomist, and Assistant Research Agronomist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 785.

## VARIATION IN FLIES AND MANURE

Preliminary trials showed that it was difficult to obtain equal infestation of eggs in similar samples of manure naturally exposed to flies. The physical condition of the exposed surface of the manure greatly influenced the choice made by the fly in laying its eggs, especially in small experimental samples. In most trials attempts were made to simulate actual barn conditions by using large amounts of manure as nearly uniform in character as possible. In most cases a known number of eggs were planted in the manure, thus insuring uniformity and comparability in this respect. The hatch of flies depends to a large extent on the weather. Under Vermont conditions good hatches were certain only in midsummer.

To overcome variation in flies as much as possible, a dependable source of flies is necessary. Eggs were obtained from fresh horse manure, a small pile of which, exposed to flies, was found to supply all that were necessary. Egg clusters thus obtained were carefully placed among the surface cracks of the manure, but not mixed into the mass under test. While strips of meat and other moist protein substances readily attract flies and offer a good means for obtaining eggs, these types of bait often attract green blow flies, a quite different genus not desirable for this study.

## BORAX FOR CONTROL OF FLIES IN CATTLE MANURE

Granular borax was mixed with fresh portions of cow manure in amounts equal to 1, 2, 4, 5, and 6 pounds per ton of manure. These five mixtures, together with an untreated check, were placed in 2-gallon stoneware jars and each inoculated with about 400 fly eggs. A fly trap was then placed securely on the top of each jar until such time as the flies ceased to hatch. The numbers of mature flies caught in the traps are shown in Table 1.

TABLE 1.—*Effect of increasing rates of borax on the control of flies in cattle manure, approximately 400 eggs added to each jar.*

| Borax per ton of manure, lbs. | Number of flies hatched |
|---|---|
| None | 400 |
| 1 | 405 |
| 2 | 385 |
| 4 | 100 |
| 5 | 80 |
| 6 | 10 |

These data show that unless at least 4 pounds of borax per ton of manure were used multiplication of flies was not reduced. When 6 pounds were used, the number of flies was drastically cut. This amount, on a volume basis, is similar to that suggested by Bishopp (1) and Cook, *et al.* (2) in which they used 0.62 pound of borax per 8 bushels of *horse* manure. They dissolved the borax in about 10 gallons of water and sprinkled this upon the manure. For such manure it may be necessary to dissolve the borax first since there is insufficient liquid for adequate penetration of borax in relatively

dry horse manure. Since borax dissolves very slowly in cold water, it would be quite difficult, if not impossible, to apply it thus in the average dairy barn.

Since borax acts as a poison to the fly larvae, it should be well distributed at points where they feed. The adult flies which emerged from the treated manure in the writers' trials apparently were able to avoid areas containing the highest concentration of borax.

Several preliminary trials indicate that borax is more effective if sprinkled in the bottom of the cleaned gutter. Thus placed, the urine is better able to dissolve the borax and it becomes well mixed with the manure when removed from the stable. Further work needs to be done along this line.

## BORIC ACID FOR CONTROL OF FLIES IN CATTLE MANURE

Theoretically, boric acid should be more effective than borax as a manurial amendment. It is a weak acid and, to some extent, inhibits nitrogen escape into the air; in fact it is sometimes used for this purpose in Kjeldahl nitrogen determinations (3). Borax, on the other hand, is alkaline and tends to drive some ammonia from manure. Boric acid is more readily soluble than borax and contains half again as much boron. Hence, an equivalent amount of boron can be more readily dissolved in the form of boric acid.

### MIXED WITH MANURE

One hundred-pound quantities of fresh cow manure were each thoroughly mixed with boric acid at rates of 2½ and 5 pounds per ton of manure. A similar amount of manure was left untreated for comparison. All lots were exposed to flies for 6 days for natural egg inoculation and then covered with fly traps. The trial was carried on simultaneously in two dairy barns. The number of mature flies hatched and trapped are shown in Table 2.

TABLE 2.—*Effect of mixing boric acid with manure on the multiplication of flies.**

| Boric acid per ton of manure, lbs. | Number of flies hatched | |
|---|---|---|
| | Barn No. 1 | Barn No. 2 |
| None | 5,800 | 658 |
| 2.5 | 500 | 110 |
| 5 | 20 | 16 |

*Exposed 6 days to flies; no eggs added.

The use of boric acid at the rate of 2.5 pounds per ton of manure materially reduced fly numbers, while very few survived when 5 pounds were applied. Many more flies were seen near barn No. 1 than around barn No. 2 which, no doubt, accounts for the larger number hatched in the former case. These data give striking evidence of the rate at which flies may multiply in small amounts of untreated manure, nearly 6,000 emerging from 100 pounds.

### BORIC ACID IN GUTTER

Boric acid to be most effective should be completely dissolved and well distributed in the manure. This might be accomplished by applying it in the bottom of the barn gutter where the urine may come into contact with it, especially in water tight gutters. It might be possible thus to effect a better control of flies than by mixing boric acid with the manure. Therefore, boric acid in amounts equivalent to 2.5 and 5 pounds per ton of manure was used under actual barn conditions in the cleaned gutter. One hundred pound portions of manure produced in the treated and untreated gutters were placed in large cans (ash barrels), inoculated with about 1,500 eggs, and then covered with fly traps. A similar trial was conducted at a later date in which smaller quantities of manure were employed with only about 500 fly eggs (Fig. 1). The results from these two trials are presented in Table 3.

TABLE 3.—*Effect of boric acid in the gutter on the control of flies.*

| Boric acid per ton of manure, lbs. | Number of flies hatched from | |
|---|---|---|
| | About 1500 eggs 1st trial | About 500 eggs 2nd trial |
| None | 1,559 | 518 |
| 2.5 | 20 | 28 |
| 5.0 | 3 | 0 |

These data definitely show that 2.5 pounds of boric acid per ton of manure is very effective in reducing the fly population. Sprinkling

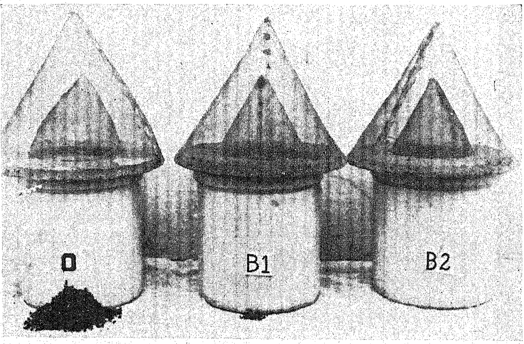


FIG. 1.—Effect of mixing boric acid with manure on the multiplication of flies. O, no boron; B1, boric acid 2.5 pounds per ton of manure; B2, boric acid 5 pounds per ton of manure.

of boric acid in the gutter appears more effective than subsequent mixing with the manure (Table 2), although the trials were so conducted that the results are not directly comparable.

### BORIC ACID APPLIED TO OUTSIDE OF A MANURE PILE

Manure piles are ideal breeding places for flies. Since the larvae feed near the surface, it should be possible to poison them by applying boric acid to the outside of the pile. Preliminary trials showed that tight wood or concrete floors were needed for experiments since the larvae may travel a considerable distance from the pile if it is in contact with the soil. This is particularly true just previous to the pupation period.

Dry boric acid equivalent to 5 pounds per ton of manure was spread over a 250-pound conical pile, a similar pile being left untreated. An attempt was made to dissolve the boric acid by sprinkling a little water over the entire pile, an equivalent amount of water being also applied over the untreated manure. The piles were left exposed to natural infestation for 4 days and then covered with large screen cages containing suitable fly traps. The data relative to flies caught are presented in Table 4.

TABLE 4.—*Effect on control of flies of applying boric acid to the outside of the manure pile.*

| Boric acid per ton of manure | Number of flies hatched |
|---|---|
| None | 3,530 |
| 5 pounds on top of pile; watered-in | 515 |

The results show that the application of boric acid to the outside of a manure pile, followed with some water, markedly reduced the fly population but was less effective than the other methods tried. Only one trial was made. The boric acid may not have been thoroughly dissolved and carried down into the manure. Better control might result if it was dissolved before use.

When applied to the outside of the pile, much of the boric acid is concentrated in the surface area. However, it must be present in the moist feeding range of the larvae in order to poison them. In actual practice this may be accomplished during a heavy rain, but since flies may complete their life cycle within a week or two, one should not depend upon rain for dissolving and carrying the boric acid into the pile. If a manure pile is to be treated, the writers suggest that the boric acid be dissolved in water (preferably warm) before applying. The larvae feed near the surface where they can obtain air; thus, it is not necessary to poison or treat the central portion of the pile.

### DISCUSSION

Cow manure containing ordinary amounts of bedding offers a very good breeding medium for flies. Thus, in one instance, nearly 6,000 flies hatched from 100 pounds of manure which had been exposed in the barn for 6 days. Many generations of flies may be produced in one

season since a new one may start every 2 weeks. Temperature, humidity, and character and abundance of food control the number of flies produced. Since flies may feed and breed in human excrement, they are potential carriers of many diseases including polio, the virus of which may occur in human bowel discharges.

Flies are best controlled by destroying their breeding places or rendering them incapable of supporting larval growth. Manure hauled daily in the summer and spread thinly dries quickly. This is fortunate since it checks the multiplication of flies. However, summer is a busy time on the farm. Furthermore, many eggs are laid in the manure while it lies in the gutter and these may hatch within 24 hours. If the larvae attain a fairly good size before the manure completely dries in the field, they can continue to develop and to pupate in the soil. Because of these circumstances, poisoning of the larvae in the manure is necessary for effective checking of reproduction. Borax or boric acid serve well for this purpose since their use reduces fly numbers and at the same time provide boron for crop growth. Previous studies have shown that under Vermont conditions, boron contributes to the maintenance of successful alfalfa stands (4, 6).

Boric acid seems to control flies better than borax, being more soluble and containing more boron per unit weight. Moreover, it results in some saving of nitrogen whereas alkaline borax tends to drive off nitrogen. Both seemed most effective when sprinkled in the stable gutter, being thus dissolved by the urine and becoming well mixed with the manure. An easy way to apply the small amount needed is to use a quart can with suitable holes in the bottom for spreading. A quart of borax weighs about 2 pounds. If piled manure is treated, the material should be dissolved in water and then the water sprinkled over the exterior.

There are definite limits to the amount of either borax or boric acid that can be safely tolerated in manure used as a fertilizer. An overdose will harm crops, but 2.5 to 3 pounds of boric acid or an equivalent amount of borax per ton of manure should not be injurious to alfalfa if not more than 10 tons of manure per acre are used in the field. Twice as much borax has been used on alfalfa with helpful rather than harmful results. Other crops may be less tolerant. Since only summer-produced manure need be treated for fly control and since there is little voided in the stable during that season of the year, this small amount of borated manure could well be used on alfalfa, orchards, or soils recently limed. Liming tends to increase the need of crops for boron and also reduces toxicity if too much boron is used (5). By exercising care to see that 30 to 40 pounds of boric acid per acre or its borax equivalent is not exceeded in the field, these materials applied in the barn gutter can be made to serve the dual purpose of summer fly control and of providing fertilizer boron for alfalfa.

## SUMMARY

Borax and boric acid were tested for the control of flies in cattle manure.

It was found necessary to plant a known number of fly eggs in the surface cracks of the manure samples under test to insure experi-

mental uniformity in eggs. A pile of exposed fresh horse manure provided an ample supply of eggs.

Boric acid was more effective than granular borax on the same boron basis. This is probably because the acid is more soluble.

Best results were obtained when 2½ to 3 pounds of boric acid per ton of manure were placed in the bottom of the cleaned barn gutter. In this position the material dissolves in the urine and thus insures better subsequent mixing with the manure. This amount of boric acid gave good fly control and at the same time the treated manure is a good source of boron for alfalfa and orchards when used at rates not exceeding 10 tons per acre. Only summer-produced manure need be treated in this way.

Piled manure left during the summer is an ideal breeding ground for flies. If this manure cannot be spread, the surface should be sprayed or sprinkled with borax or boric acid in solution at the above rates.

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# GERMINATION OF 20-YEAR-OLD WHEAT, OATS, BARLEY, CORN, RYE, SORGHUM, AND SOYBEANS[1]

D. W. ROBERTSON, A. M. LUTE, AND H. KROEGER[2]

THE knowledge that farm seeds when stored in a dry atmosphere maintain their viability over a long period of years may be of value in the storage of reserve seed stocks to meet war and post-war needs. The data reported in this paper are from a study of seeds stored for periods varying from 1 to 22 years.

The literature on storage of farm seeds was reviewed in previous papers by the authors and will not be discussed here.[3] Previous results[4] have shown that seeds of wheat, oats, and barley stored under arid climatic conditions declined slowly for the first 10-year period with a sharp break in germination between the tenth and twelfth years. There were indications of different reactions to storage between six-rowed hulled, two-rowed hulled, and six-rowed hulless barley.

Rosen rye and Wisconsin Black soybeans did not maintain their viability to the same degree as wheat, oats, and barley.

Black Amber sorghum still maintained an excellent germination percentage after being stored for 10 years, and Yellow Dent corn germinated well for the first 6 years and dropped off rapidly between the ninth and tenth years. The results reported in this paper are a continuation of the previous work reported by the authors.

## EXPERIMENTAL METHODS

The first tests were made in 1921 on the 1920 crop. The grains were threshed, cleaned, and stored in 100-pound sacks, which were then placed in an unheated room. They were stored in the same room during the entire period of the test. Samples were taken in February of each succeeding year. Composite samples from each sack were made by mixing grain drawn from the sacks by a grain probe and by taking off a portion with a small scoop. Germination tests were made before July 1 of each year. Crops from the succeeding years, 1920–29, were saved when grown and placed in the storage room. Only perfect seeds were used for germination, broken and damaged seeds being discarded. In the later years of the experiment, considerable damage was done by the dermestid beetle (*Trogoderma tarsale*). All damaged seeds were discarded. The storage room was sprayed with an ethylene dichloride-carbon tetrachloride mixture to control insect pests.[5] The crops used were the standard varieties of cereals shown in Table 1.

[1]Contribution from the Section of Agronomy, Colorado Agricultural Experiment Station, Fort Collins, Colo. Authorized by the Director of the Colorado Agricultural Experiment Station for publication as Scientific Journal Series Article No. 162. Received for publication April 3, 1943.

[2]Agronomist, formerly Seed Analyst, and Seed Analyst, respectively.

[3]ROBERTSON, D. W., and LUTE, ANNA M. Germination of the seed of farm crops in Colorado after storage for varying periods of years. Jour. Agr. Res., 45:455–462. 1932.

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[5]The mixture used was ethylene dichloride 3 parts and carbon tetrachloride 1 part by volume, according to Roark, R. C., and Cotton, R. T. Tests of various alipathic compounds as fumigants. U. S. D. A. Tech. Bul. 162. 1929.

TABLE 1.—*Varieties of seed studied and years in which they were grown.**

| Crop | Variety | 1920 | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Spring wheat... | Marquis | | + | + | + | + | + | + | + | | + |
| Winter wheat... | Kanred | | + | | | + | | | | | + |
| Spring wheat... | Defiance | | | + | | + | | + | + | | |
| Durum wheat... | Kubanka | | + | + | | | | | | | + |
| Oats...... | Colorado 37 | + | | + | + | + | + | + | + | + | + |
| | Great Dakota | | | + | + | | | | | | |
| | Swedish Victory | + | | + | | | | | | | |
| | White Russian | + | | | | | | | | | |
| | Gold Rain | | | | | | + | + | | | |
| | Nebraska 21 | | | + | | + | + | + | + | + | + |
| Barley..... | Nepal | + | + | + | + | + | + | | | | |
| | Success | + | + | + | | | | | | | |
| | Colsess | | | + | + | + | + | + | + | + | + |
| | Coast | + | + | | + | + | + | | | | |
| | Hanna | + | | + | | | | | | | |
| | Gold | + | | | | | | | | | |
| | Moister | | | | | | + | + | + | | |
| Winter rye. | Rosen | | | + | + | + | | | | + | |
| Soybean... | Wisconsin Black | | | | + | + | | | | | |
| Sorghum .. | Black Amber | | | | | | + | + | + | | |
| Corn...... | Yellow dent | | + | + | + | + | | | | | |

*Plus mark signifies crop was grown in year indicated.

From an examination of the humidity records, there appears to be no connection between the average annual relative humidity and the original germination percentage. Humidities for all years were low. The actual percentage of moisture in the seed samples was determined for the 1929 crop and was found to range between 9.5 and 11.4. No tests were made on the other crops. In later studies, Robertson, Lute and Gardner[6] found there was a close relationship between the relative humidity and moisture content of the grain. The 1929 figures would, therefore, indicate that the relative humidity in the storage room was very low.

## RESULTS

The germination tests made the year the seeds were harvested ranged from 93.0 to 98.5% for Marquis, 84.0 to 90.0% for Kubanka, and 93.0 to 95.0% for Kanred wheat (Table 2). Barley and rye showed a greater variation than wheat and oats from year to year and for different varieties. The germination percentage of oats did not differ greatly from that of wheat.

The general trend seems to indicate that oats, barley (covered), and Marquis and Kanred wheat have a high percentage of germination the first year, while Kubanka wheat, Nepal barley (naked), and Rosen rye show a lower germination percentage the first year.

[6]ROBERTSON, D. W., LUTE, A. M., and GARDNER, ROBERT. Effect of relative humidity on viability, moisture content, and respiration of wheat, oats, and barley seed in storage. Jour. Amer. Soc. Agron., 59:281–292. 1939.

The germination percentages of wheat, oats, and barley are presented in Table 3 and are shown graphically in Fig. 1. The general trend of all the crops is similar. Germination holds up for the first 10 years, dropping only about 5% lower than the original germination. In the next 5 years the drop is greater, as is indicated by the increased slope of the curve in Fig. 1. Wheat dropped more in germination percentage than did either oats or barley. From the fifteenth to the twenty-first years wheat dropped from 72% to 12%, while oats and barley dropped from about 80% to between 40 and 50%. These data indicate that wheat, oats, and barley hold up their germination for a 10-year period when stored under climatic conditions prevailing at Fort Collins, Colo. When 15 years old they may be considered to have sufficient viability to justify their planting in the field. In the next six years (fifteenth to twenty-first years), wheat loses its germination rather rapidly, but barley and oats still germinate about 50%. The small number of crops after the thirteenth year reduce the value of the data somewhat, but at the end of the period we still have three wheat crops, three oat crops, and five barley crops. At 13 years, each dot on the curve (Fig. 1) represents the following number of crops tested: For wheat, 18; for oats, 23; and for barley, 32.

The data in Table 3 show the germination percentages calculated as a percentage of the first year's germination. This accounts for the apparent increase in germination percentage in some of the varieties. The standard error was calculated from the actual percentage germination for the first year and from the calculated percentages for the other years. The results for the corn crop give actual germination throughout. The same is true of White Russian oats. Unfortunately, germination tests were not obtained the first year on some of the corn and on White Russian oats, so calculations could not be made on the basis of 1-year-old seed.

## DISCUSSION

### WHEAT VARIETIES

The comparative percentage germination of the various crops is given in Table 3. As previously mentioned, the number of crops tested drops off as the crops increase in age. This is due to the fact that they were produced in different years over a 10-year period. The fact that fewer crops are available as they advance in age may have some influence on the value of the data from the older crops. However, the trend seems to be consistent for all crops tested. Three varieties of *Triticum vulgare* and one variety of *T. durum* are represented in the table. When we consider the average germination of all wheat varieties tested, it will be noted that the germination drops slightly each year until the twelfth year and then takes a marked drop. This is also shown in Fig. 1.

When we consider the drop in germination percentage by 5-year periods, it will be noted that there is a decline of 2.8 for the first 5-year period, 5.3 for the second 5-year period, 27.6 for the third 5-year period, and 76.0 for the fourth 5-year period.

The different varieties when analyzed separately show a similar trend and do not present any marked varietal difference for the first 20 years.

BARLEY VARIETIES

The results of the tests of barley varieties are shown in Table 3. The average germination of all barleys in percentage shows a gradual decline for the first 12-year period with a slight drop for the next 3 years and a sharp drop for the next 7 years. This is shown graphically in Fig. 1. When the germination data are examined, it will be seen that a drop of 6.6% was obtained for the first 10 years and 14.3% in the next 5 years, with a drop of 49.1% in the 5-years between 15 and 20 years. In Table 3 the various types of barley are grouped. It will be noted that the six-row covered hooded barleys and the six-rowed covered awned barleys are somewhat higher in germination throughout than the average for all barleys.

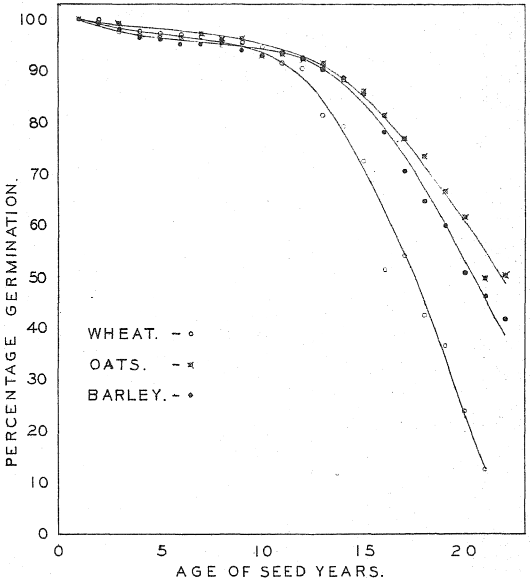


FIG. 1.—Curves showing the relationship between age of seed in years and percentage germination of wheat, oats, and barley.

TABLE 2.—*Germination percentages for various crops harvested in different years.*

| Variety | 1920 | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Wheat | | | | | |
| Marquis | — | 98.0 | 97.5 | 93.0 | 93.5 | 97.5 | 95.5 | 98.5 | — | 97.0 |
| Defiance | — | — | 96.0 | — | 89.0 | — | 90.5 | 98.5 | — | — |
| Kanred | — | 95.0 | — | — | 94.0 | — | — | — | — | 93.0 |
| Kubanka | — | 88.0 | 90.0 | — | — | — | — | — | — | 84.0 |
| | | | | | Barley | | | | | |
| Nepal | 87.0 | 95.5 | 95.0 | 73.0 | 69.0 | 84.0 | — | — | — | — |
| Success | 98.5 | 99.5 | 96.0 | — | — | — | — | — | — | — |
| Colsess | — | — | 99.5 | 98.5 | 97.0 | 97.0 | 94.0 | 97.0 | 97.0 | 99.5 |
| Coast | 97.0 | 94.0 | — | 98.5 | 92.0 | 96.5 | — | — | — | — |
| Trebi | — | — | — | — | — | — | 97.0 | — | — | 91.5 |
| Hanna | 90.5 | — | 96.0 | — | — | — | — | — | — | — |
| Gold | 95.5 | — | — | — | — | — | — | — | — | — |
| Moister | — | — | — | — | — | 98.5 | 96.0 | 97.0 | — | — |
| Elfry | — | — | — | — | — | 99.5 | — | — | — | — |
| Smyrna | — | — | — | — | — | — | — | 91.5 | — | — |
| | | | | | Oats | | | | | |
| Colorado 37 | 98.0 | — | 99.0 | 99.0 | 98.0 | 97.0 | 97.0 | 95.0 | 98.5 | 98.0 |
| Nebraska 21 | — | — | 97.0 | — | 97.5 | 95.5 | 94.0 | 98.0 | — | 92.0 |
| Swedish Victory | 99.0 | — | 99.5 | — | — | — | — | — | — | — |
| Gold Rain | — | — | — | — | — | 95.5 | 97.0 | — | — | — |
| Great Dakota | — | — | 99.5 | 99.0 | — | — | — | — | — | — |
| | | | | | Miscellaneous Crops | | | | | |
| Rosen rye | — | — | 98.0 | 83.5 | 84.0 | — | — | — | — | 83.5 |
| Wisc. Black soybeans | — | — | — | 93.5 | — | — | — | — | — | — |
| Black Amber sorghums | — | — | — | — | — | — | — | 62.0 | — | — |
| Minn. 13 corn | — | — | — | 85.0 | 98.0 | — | — | — | — | — |

The naked barleys are lower throughout. The two-rowed barleys hold up for the first 5-year period but drop noticeably in the last 15-year period. From these data it may be concluded that the varieties tested show some varietal differences in their ability to maintain viability over a period of 20 years. Nepal C.I. 595 and the two-rowed barleys, Gold and White Smyrna, drop off much quicker in germination after the first 5-year period of storage.

## OAT VARIETIES

Both midseason and early oats are included in the test. Unfortunately, when the study was started red oats, *A. byzentina*, were not being grown extensively in Colorado, and therefore, were not included in the studies. As will be seen from Table 3 and Fig. 1, oats followed very closely the same type of decrease as did barley. A drop of 2.5% was noted in the first 5-year period, 5.9% in the second period, 14.0% in the third period, and 38.4% in the fourth period. The germination percentage in the twentieth year is the average of seven samples.

OTHER CROPS

The data obtained on the other crops are less complete, and the number of crop years per crop is less. The data from dent corn, rye, sorghum, and soybeans is given in Table 3 and graphically in Fig. 2. It will be noted from Fig. 2 that corn (actual germination) drops off rather uniformly for the 21-year period of the test. Unfortunately, the test is not as complete as some of the others, but at the end of 21

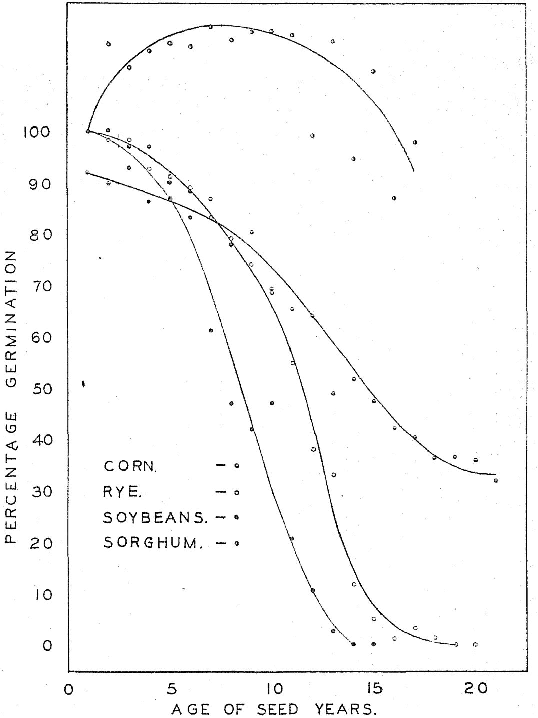


FIG. 2.—Curves showing the relationship begween age of seed in years and percentage gernimation for corn, rye, soybeans, and sorghums.

TABLE 3.—*Comparative percentage germination and number of crops tested in indicated number of years after harvest.*

| Variety | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Wheat** | | | | | | | | | | | | | | | | | | | | | | |
| Marquis C. I. 3641: | | | | | | | | | | | | | | | | | | | | | | |
| Germination, %... | 100 | 99.8 | 98.2 | 96.0 | 97.0 | 96.5 | 95.4 | 94.6 | 95.7 | 94.8 | 92.0 | 90.2 | 80.8 | 78.8 | 63.4 | 56.5 | 49.4 | 46.6 | 35.1 | 26.1 | 11.2 | — |
| No. crops tested.... | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 7 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | — |
| Defiance: | | | | | | | | | | | | | | | | | | | | | | |
| Germination, %... | 100 | 98.4 | 99.3 | 98.2 | 97.3 | 97.0 | 98.7 | 96.5 | 97.4 | 94.7 | 89.6 | 91.8 | 88.9 | 81.8 | 68.2 | 57.1 | 71.0 | 38.7 | 20.8 | 9.4 | — | — |
| No. crops tested.... | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 2 | 2 | 1 | 1 | — | — |
| Kanred C. I. 5146: | | | | | | | | | | | | | | | | | | | | | | |
| Germination, %... | 100 | 102.5 | 98.4 | 101.4 | 97.5 | 98.3 | 97.0 | 94.1 | 95.8 | 98.4 | 93.4 | 90.9 | 75.1 | 67.9 | 70.4 | 54.5 | 54.0 | 27.5 | 15.8 | 12.6 | 2.1 | — |
| No. crops tested.... | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | — |
| Kubanka C. I. 1440: | | | | | | | | | | | | | | | | | | | | | | |
| Germination, %... | 100 | 100.6 | 94.5 | 97.5 | 97.5 | 97.7 | 98.1 | 95.0 | 87.6 | 90.9 | 91.4 | 88.7 | 81.3 | 87.1 | 78.2 | 63.4 | 49.0 | 54.6 | 57.9 | 34.9 | 25.0 | — |
| No. crops tested.... | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | |
| All varieties: | | | | | | | | | | | | | | | | | | | | | | |
| Germination, %... | 100 | 100.1 | 97.9 | 97.7 | 97.2 | 97.1 | 96.8 | 95.0 | 95.7 | 94.7 | 91.6 | 90.4 | 81.7 | 79.2 | 72.4 | 51.4 | 54.1 | 42.8 | 36.8 | 24.0 | 12.8 | — |
| No. crops tested.... | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 15 | 14 | 13 | 11 | 10 | 7 | 6 | 3 | — |
| S. E. of mean...... | 0.97 | 0.67 | 0.88 | 1.02 | 0.92 | 0.96 | 1.29 | 0.82 | 1.22 | 1.10 | 1.03 | 1.60 | 2.57 | — | — | — | — | — | — | — | — | — |
| **Barley** | | | | | | | | | | | | | | | | | | | | | | |
| Nepal C. I. 595: | | | | | | | | | | | | | | | | | | | | | | |
| Germination, %... | 100 | 99.3 | 89.8 | 86.2 | 88.3 | 85.9 | 90.4 | 93.4 | 89.1 | 86.5 | 93.7 | 88.5 | 87.8 | 82.7 | 77.3 | 65.0 | 54.5 | 46.8 | 38.2 | 32.7 | 24.5 | 13.8 |
| No. crops tested.... | 6 | 6 | 4 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 5 | 4 | 3 | 2 | 1 |
| Success: | | | | | | | | | | | | | | | | | | | | | | |
| Germination, %... | 100 | 97.8 | 95.3 | 97.0 | 98.5 | 94.1 | 96.4 | 94.9 | 89.8 | 91.5 | 89.6 | 89.6 | 90.3 | 89.2 | 90.8 | 86.5 | 78.5 | 74.2 | 72.2 | 64.3 | 60.2 | 53.8 |
| No. crops tested.... | 3 | 3 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 1 |
| Colsess C. I. 2792: | | | | | | | | | | | | | | | | | | | | | | |
| Germination, %... | 100 | 98.5 | 98.0 | 98.5 | 97.6 | 97.9 | 97.2 | 97.5 | 97.0 | 97.6 | 96.7 | 95.3 | 94.5 | 93.0 | 90.8 | 82.6 | 80.4 | 80.6 | 72.2 | 70.4 | — | — |
| No. crops tested.... | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | — | — |
| Coast: | | | | | | | | | | | | | | | | | | | | | | |
| Germination, %... | 100 | 100.5 | 100.1 | 99.6 | 98.6 | 98.8 | 98.3 | 98.4 | 98.2 | 97.9 | 97.1 | 97.1 | 97.0 | 97.2 | 92.9 | 88.9 | 87.3 | 84.8 | 79.7 | 69.8 | 66.6 | 71.1 |
| No. crops tested.... | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 3 | 2 | 2 | 1 |
| Trebi C. I. 936: | | | | | | | | | | | | | | | | | | | | | | |
| Germination, %... | 100 | 96.1 | 100.7 | 97.0 | 100.9 | 99.8 | 99.1 | 97.2 | 99.0 | 99.8 | 94.5 | 98.2 | 95.1 | 79.4 | 86.6 | 82.5 | — | — | — | — | — | — |
| No. crops tested.... | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | — | — | — | — | — | — |

| | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Hanna:** | | | | | | | | | | | | | | | | | | | | | | |
| Germination, % | 100 | 97.2 | 104.2 | 99.0 | 100.4 | 94.9 | 90.2 | 90.8 | 90.7 | 86.6 | 87.1 | 84.1 | 80.8 | 76.5 | 73.3 | 62.9 | 52.4 | 45.9 | 54.4 | 38.4 | 33.1 | 32.0 |
| No. crops tested | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 |
| **Gold C. I. 1145:** | | | | | | | | | | | | | | | | | | | | | | |
| Germination, % | 100 | 97.4 | 99.5 | 98.4 | 93.7 | 87.4 | 81.0 | 79.1 | 78.0 | 68.1 | 74.9 | 84.3 | 66.5 | 69.1 | 66.0 | 57.6 | 51.3 | 37.7 | 38.7 | 33.5 | 33.5 | 38.7 |
| No. crops tested | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **Moister C. I. 2799:** | | | | | | | | | | | | | | | | | | | | | | |
| Germination, % | 100 | 99.8 | 99.3 | 99.6 | 95.6 | 97.6 | 96.1 | 96.3 | 96.4 | 91.6 | 94.0 | 93.7 | 88.9 | 93.1 | 91.3 | 87.0 | 81.2 | — | — | — | — | — |
| No. crops tested | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 1 | — | — | — | — | — |
| **Elfry C. I. 2800:** | | | | | | | | | | | | | | | | | | | | | | |
| Germination, % | 100 | 100 | 99.0 | 96.5 | 89.4 | 95.0 | 94.5 | 93.0 | 92.5 | 91.5 | 88.4 | 86.4 | 81.4 | 85.4 | 77.4 | 86.4 | 79.4 | — | — | — | — | — |
| No. crops tested | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | — | — | — | — | — |
| **White Smyrna:** | | | | | | | | | | | | | | | | | | | | | | |
| Germination, % | 100 | 106.6 | 102.7 | 106.0 | 104.9 | 104.9 | 102.7 | 103.8 | 102.7 | 100.5 | 95.6 | 102.7 | 92.9 | 97.3 | 88.5 | — | — | — | — | — | — | — |
| No. crops tested | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | — | — | — | — | — | — | — |
| **All barleys:** | | | | | | | | | | | | | | | | | | | | | | |
| Germination, % | 100 | 99.1 | 98.1 | 96.4 | 96.1 | 95.1 | 95.2 | 95.6 | 94.1 | 93.4 | 93.6 | 92.7 | 90.5 | 88.8 | 85.7 | 78.2 | 70.7 | 64.8 | 60.0 | 50.9 | 46.2 | 41.9 |
| No. crops tested | 32 | 31 | 28 | 31 | 31 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 30 | 29 | 26 | 22 | 18 | 15 | 12 | 8 | 5 |
| S. E. of mean | 1.24 | 0.63 | 0.91 | 1.32 | 1.21 | 1.30 | 1.80 | 1.57 | 1.57 | 1.86 | 1.61 | 1.93 | 1.86 | 2.23 | 2.28 | — | — | — | — | — | — | — |
| **Naked barleys:** | | | | | | | | | | | | | | | | | | | | | | |
| Germination, % | 100 | 99.3 | 89.8 | 86.2 | 88.3 | 85.9 | 90.4 | 93.4 | 89.1 | 86.5 | 93.7 | 88.5 | 87.8 | 82.8 | 77.3 | 65.0 | 54.5 | 46.8 | 38.2 | 32.7 | 24.5 | 13.8 |
| No. crops tested | 6 | 6 | 4 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 5 | 4 | 3 | 2 | 1 |
| **6-rowed hulled hooded barley:** | | | | | | | | | | | | | | | | | | | | | | |
| Germination, % | 100 | 98.3 | 97.7 | 98.2 | 97.8 | 96.9 | 96.9 | 96.9 | 95.0 | 95.9 | 94.7 | 93.8 | 93.3 | 91.8 | 90.8 | 84.0 | 79.6 | 77.4 | 72.2 | 65.8 | 60.2 | 53.8 |
| No. crops tested | 11 | 11 | 9 | 10 | 10 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 2 | 1 |
| **6-rowed hulled awned barley:** | | | | | | | | | | | | | | | | | | | | | | |
| Germination, % | 100 | 99.5 | 100 | 98.9 | 97.5 | 98.3 | 97.5 | 97.1 | 97.3 | 96.0 | 95.0 | 95.4 | 93.0 | 93.0 | 90.2 | 87.5 | 85.3 | 84.8 | 79.7 | 69.8 | 66.6 | 71.1 |
| No. crops tested | 11 | 11 | 9 | 10 | 10 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 11 | 10 | 10 | 9 | 7 | 4 | 3 | 2 | 2 | 1 |
| **2-rowed hulled awned barley:** | | | | | | | | | | | | | | | | | | | | | | |
| Germination, % | 100 | 98.4 | 102.6 | 100.6 | 99.8 | 95.5 | 91.0 | 91.1 | 90.5 | 80.4 | 83.0 | 84.1 | 76.0 | 74.0 | 70.8 | 61.1 | 52.0 | 43.2 | 49.1 | 36.7 | 33.3 | 35.4 |
| No. crops tested | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 2 | 2 |
| | | | | | | | | | | | Oats | | | | | | | | | | | |
| **Colorado 37:** | | | | | | | | | | | | | | | | | | | | | | |
| Germination, % | 100 | 100.1 | 99.4 | 98.0 | 97.6 | 97.2 | 98.6 | 95.9 | 97.1 | 95.2 | 94.7 | 92.7 | 91.8 | 89.1 | 85.6 | 81.7 | 80.5 | 72.8 | 64.8 | 71.0 | 59.2 | 60.2 |
| No. crops tested | 9 | 8 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 1 |
| **Nebraska 21:** | | | | | | | | | | | | | | | | | | | | | | |
| Germination, % | 100 | 100.6 | 99.1 | 98.4 | 98.6 | 98.3 | 97.9 | 97.4 | 97.0 | 95.5 | 91.3 | 92.4 | 90.2 | 88.1 | 81.5 | 78.2 | 64.8 | 61.6 | 67.0 | 53.6 | | |
| No. crops tested | 6 | 6 | 7 | 7 | 6 | 7 | 7 | 7 | 7 | 6 | 7 | 7 | 6 | 5 | 5 | 4 | 3 | 2 | 1 | 1 | | |

*Actual germination on two samples of Northwestern Dent and four samples of Yellow Dent.

TABLE 3.—*Concluded.*

| Variety | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Oats—*Continued*** | | | | | | | | | | | | | | | | | | | | | | |
| Swedish Victory: | | | | | | | | | | | | | | | | | | | | | | |
| Germination, % | 100 | 95.0 | 99.3 | 97.8 | 93.5 | 92.7 | 94.5 | 92.7 | 91.0 | 88.7 | 93.2 | 88.4 | 92.5 | 87.4 | 90.7 | 81.6 | 80.1 | 77.6 | 75.6 | 69.0 | 65.7 | 65.7 |
| No. crops tested | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 |
| Gold Rain: | | | | | | | | | | | | | | | | | | | | | | |
| Germination, % | 100 | 99.5 | 99.9 | 97.1 | 98.5 | 96.6 | 97.1 | 99.5 | 98.4 | 100.3 | 94.0 | 97.2 | 95.6 | 95.1 | 94.0 | 93.5 | 78.5 | — | — | — | — | — |
| No. crops tested | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | — | — | — | — | — |
| Great Dakota: | | | | | | | | | | | | | | | | | | | | | | |
| Germination, % | 100 | 97.8 | 97.8 | 95.7 | 96.5 | 94.8 | 93.0 | 95.5 | 91.9 | 86.7 | 93.5 | 90.2 | 88.2 | 85.2 | 84.2 | 77.6 | 82.6 | 75.1 | 80.1 | 74.4 | — | — |
| No. crops tested | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | — | — |
| White Russian: | | | | | | | | | | | | | | | | | | | | | | |
| Germination, % | — | 98.5 | — | 97.0 | 98.0 | 95.0 | 93.5 | 94.5 | 97.5 | 88.0 | 95.0 | 89.5 | 95.5 | 78.5 | 88.0 | 77.0 | 76.0 | 54.0 | 28.0 | 23.0 | 24.0 | 25.0 |
| No. crops tested | — | 1 | — | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| All varieties: | | | | | | | | | | | | | | | | | | | | | | |
| Germination, % | 100 | 99.6 | 99.2 | 97.8 | 97.5 | 96.8 | 97.2 | 96.3 | 96.2 | 94.1 | 93.4 | 92.2 | 91.6 | 88.4 | 86.0 | 81.5 | 76.9 | 73.5 | 66.7 | 61.6 | 49.6 | 50.3 |
| No. crops tested | 21 | 20 | 22 | 23 | 22 | 23 | 23 | 23 | 23 | 22 | 23 | 23 | 22 | 20 | 19 | 17 | 14 | 11 | 9 | 7 | 3 | 3 |
| S. E. of mean | 0.43 | 0.69 | 0.62 | 0.78 | 0.82 | 0.83 | 0.87 | 0.90 | 0.82 | 1.28 | 1.10 | 1.07 | 1.02 | — | — | — | — | — | — | — | — | — |
| **Rye** | | | | | | | | | | | | | | | | | | | | | | |
| Rosen: | | | | | | | | | | | | | | | | | | | | | | |
| Germination, % | 100 | 98.3 | 98.4 | 92.9 | 91.4 | 89.4 | 83.5 | 79.2 | 74.2 | 68.9 | 55.0 | 38.1 | 33.1 | 11.9 | 5.1 | 1.2 | 3.2 | 1.6 | 0 | 0 | — | — |
| No. crops tested | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 2 | 1 | — | — |
| **Soybeans** | | | | | | | | | | | | | | | | | | | | | | |
| Wisconsin Black: | | | | | | | | | | | | | | | | | | | | | | |
| Germination, % | 100 | 101.1 | 93.0 | 86.6 | 90.1 | 83.3 | 61.2 | 47.0 | 42.0 | 47.1 | 20.7 | 10.7 | 2.7 | 0 | 0 | — | — | — | — | — | — | — |
| No. crops tested | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | — | — | — | — | — | — | — |
| **Sorghum** | | | | | | | | | | | | | | | | | | | | | | |
| Black Amber: | | | | | | | | | | | | | | | | | | | | | | |
| Germination, % | 100 | 117.0 | 112.6 | 115.8 | 117.2 | 116.5 | 120.5 | 117.9 | 119.4 | 119.6 | 118.9 | 99.1 | 117.8 | 94.9 | 111.8 | 87.0 | 97.9 | — | — | — | — | — |
| No. crops tested | 1 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 1 | — | — | — | — | — |
| **Corn** | | | | | | | | | | | | | | | | | | | | | | |
| Corn*: | | | | | | | | | | | | | | | | | | | | | | |
| Germination, % | 92.0 | 90.0 | 97.0 | 97.0 | 87.0 | 88.4 | 86.9 | 78.0 | 80.4 | 69.6 | 65.5 | 64.1 | 49.0 | 51.7 | 47.5 | 42.2 | 40.3 | 36.3 | 36.6 | 36.0 | 32.0 | — |
| No. crops tested | 2 | 1 | 2 | 2 | 2 | 5 | 6 | 6 | 5 | 6 | 5 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 5 | 3 | 1 | — |

*Actual germination on two samples of Northwestern Dent and four samples of Yellow Dent.

years the average germination was 32.0%. This indicates that stocks having a high initial germination when kept free from insect pests in a dry atmosphere could still be propagated after storage for 21 years.

Three samples of Black Amber cane harvested in different years were included in the test. All samples were not tested the first year. The curve shows that Black Amber cane maintains its germination for 15 years and then drops off rather rapidly. The fact that an increase of over 100% is shown for sorghum in Fig. 2 is due to a low germination of one crop the first year with a much higher germination the second year for two crops and thereafter. This may be due to some inherent factor in cane seed.

The data show that Rosen rye does not have the ability to maintain its viability like the other cereal grains studied. Four samples are represented in this test. From the curve in Fig. 2 it will be noted that rye drops off about 10% in the first 5 years and rather rapidly after that date. At 15 years the germination is low, and it reaches zero by the nineteenth year.

Wisconsin Black soybeans were used in the studies. They dropped off about 10% on the first 5-year period and by the fourteenth year had reached zero. The drop was exceedingly sharp after the sixth year. It may be interesting to note that as the beans dropped in germination indications of a break-down in the fat content was noted and reported from the germination test.

## SUMMARY

Germination studies are reported on various farm crops stored for varying periods from 1 to 22 years. The crops were stored in sacks in a dry, unheated room.

The germination percentage of wheat, oats, and barley declined slowly for the first 10-year period. From the tenth to the fifteenth year wheat dropped 22.3%, oats 8.1%, and barley 7.7%. The drop was somewhat greater from the fifteenth to the twentieth year as follows: Wheat, 48.4%; oats, 24.4%; and barley, 39.5%. Twenty-one-year-old wheat germinated 12.8%, oats 49.6%, and barley 46.2% of the initial germination.

There were indications of varietal differences in germination between six-rowed hulled and two-rowed hulled and naked barley.

Rosen rye and Wisconsin Black soybeans did not maintain their viability after the first 5 years. They dropped to almost zero germination by the fifteenth year.

Black Amber cane maintained its germination for a 17-year period.

Yellow Dent corn gradually declined from the first to the twenty-first year, germinating 32% at the end of the period.

A dry, arid climate preserves germination in the farm crops studied so that stocks of wheat, oats, barley, sorghum, and corn can be stored for 20 years and still have enough viable seeds to maintain the stocks.

# THE INTERRELATIONSHIPS OF SALT CONCENTRATION AND SOIL MOISTURE CONTENT WITH THE GROWTH OF BEANS[1]

A. D. AYERS, C. H. WADLEIGH, AND O. C. MAGISTAD[2]

THE effect of various soil moisture treatments upon plant growth is of particular interest to the grower of crops on saline soils for it is possible that differences in soil moisture may either decrease or intensify the salt effect.

Even when no harmful concentrations of salt occur in the soil, there is a diversity of opinion as to the proper time to irrigate to get the best growth. The individual farmer follows a practice which he feels is best suited to his conditions and to the crop he is growing. It is the custom in many localities, for instance, to irrigate potatoes, lettuce, and other truck crops far more frequently than would be necessary on the basis of the amount of water used by the plants.

Veihmeyer (21),[3] Hendrickson and Veihmeyer (11, 12), and Conrad and Veihmeyer (3) concluded from their experiments that as long as the soil moisture was above the permanent wilting percentage moisture was available to the plant and that any fluctuations between field capacity and the permanent wilting percentage would not be reflected in fruit yield or amount of growth.

Results published by Aldrich, *et al.* (1) indicated that whenever the average soil moisture in the first 3 feet fell below 70% of the available capacity on a clay adobe soil, the rate of growth of the pear fruits was reduced. They point out, however, that their results were conditioned by the difficulty of roots in permeating this heavy soil and by the rate of moisture movement through such a soil.

Davis (4), growing nut grass in 1-gallon pots of soil at five different irrigation schedules, found that growth was reduced if the soils were allowed to dry below the moisture equivalent before they were re-wetted.

The best results with spring lettuce in Arizona were obtained by Schwalen and Wharton (20) when the soil was kept relatively moist up until the harvest period.

The relation of plant growth to variation in the available soil moisture is further complicated in those soils which contain harmful quantities of salts. As such a soil drys out, the concentration of salts in the soil solution increases. The concentration of salts in the soil solution of a soil which is at the permanent wilting percentage would be much greater than that of the same soil when only a fourth or a half of its available moisture had been utilized. These differences might easily be reflected by differences in plant growth. In other words, a plant might grow better in a saline soil which is irrigated when only

[1]Contribution from the U. S. Regional Salinity Laboratory, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, Riverside, Calif., in cooperation with the 11 western states and the Territory of Hawaii. Received for publication April 5, 1943.

[2]Assistant Chemist, Senior Chemist, and Director, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 809.

part of the available moisture has been utilized than in a similar soil in which the soil moisture is allowed to approach the permanent wilting percentage before irrigation takes place.

The material presented in this paper bears upon this complex question of soil moisture relations and plant growth in soils containing appreciable amounts of salts.

## METHODS AND MATERIALS

Thirty-six 10-gallon steel drums were each filled with 102 pounds of surface soil from a location on the grounds of the Salinity Laboratory, Riverside, Calif. This soil was mapped as Sierra loam in an early survey but probably would be designated now as Fallbrook loam. As determined by the method proposed by Richards and Weaver (18), this soil held 6.2% moisture when moistened and allowed to come to equilibrium under a tension of 15 atmospheres. This 15-atmosphere value has been shown by Richards and Weaver to be in the wilting range. The permanent wilting percentage determined with sunflower plants was 6.1 and agrees closely with the 15-atmosphere value. The moisture equivalent was 14.7%. The saturated soil paste of the original soil had a pH of 7.6. At the conclusion of the experiment the soil pH values ranged from 6.6 to 8.0, depending upon treatment and the depth at which the sample was taken. Calcium was the predominating cation in the exchange complex at the start of the experiment, and there were no accumulated soluble salts in the original soil.

### EXPERIMENTAL DESIGN

The experimental variables were four salt treatments, *viz.*, no added NaCl, 1,000 p.p.m. added NaCl on dry soil basis, 2,000 p.p.m. added NaCl on dry soil basis, and 4,000 p.p.m. added NaCl on dry soil basis; and three irrigation schedules. These schedules were as follows:

A low tension series, irrigated when only small amounts of the available moisture had been utilized by the plants as explained later; a medium tension series, irrigated when moderate amounts of the available moisture had been utilized by the plants; and a high tension series, irrigated when the plants showed severe moisture stress.

The 36 drums were divided into three blocks. This gave one drum of each combination of salt and irrigation schedule per block.

The screened (¼ inch) soil was mixed in an eccentric box with the proper amount of salts for each treatment. Besides the designated sodium chloride, 3.4 grams of potassium chloride and 10.1 grams of 18% superphosphate were added to each drum of soil. One hundred and seven pounds of the soil at a moisture content of 5% were placed in each container with the aid of a mechanical mixer and packer. Nitrate was supplied by scratching 11.3 grams of sodium nitrate into the soil surface of each drum just before the initial irrigation. These amounts of fertilizing materials corresponded to an application of 1,000 pounds of 6–8–6 fertilizer per acre.

Tensiometers were placed at depths of 4 inches and at 15 inches (bottom) of each drum in one block. Enough tap water[4] was added to bring the soil to an average moisture content of 20%. This amount wet the soil above the moisture

[4]The Riverside tap water used in this experiment is a very good quality of irrigation water. It contains only 270 p.p.m. of dissolved salts (cations 45% sodium).

equivalent but did not give any free drainage. The drums were weighed daily and when the moisture content reached a designated degree of depletion, sufficient tap water was added to reestablish the 20% level.

On January 31, 1942, after the irrigated soils had been standing for several days, six germinated dwarf red kidney beans were placed in each pot. When the seedlings were well established, they were thinned to the three most uniform in each container.

Red kidney bean plants were selected for this experiment because of (a) their high sensitivity to soil salinity, (b) their rapidity in completing the reproductive cycle, and (c) their relatively small size which permitted an equable relationship between plant size and the 10-gallons of soil used in each culture.

## MOISTURE TENSION AND TIME OF IRRIGATION

The plants maintained under low soil moisture tension conditions were watered when the soil moisture tension at the 4-inch depth reached 250 cm of water. This was found to correspond to an average moisture content of 15% for all the soil in the container, and all pots in this moisture series were watered when the moisture percentage dropped to this value. Soil-moisture tension readings taken at the bottom of the soil columns were usually lower than those taken 4 inches below the surface, but never indicated any excessive concentration of moisture. (Tensions were always greater than 50 cm of $H_2O$.) The group of plants in the medium tension series was allowed to withdraw moisture from the soil until the tensiometers at the 4-inch depth registered a soil moisture tension of 750 cm of water.[5] This corresponded to an average moisture content of 11%. A third group of plants—high tension series—was not watered until the plants were appreciably wilted by mid-morning. These plants were turgid at sunrise and always recovered after irrigation. Only in those drums in which no added sodium chloride was present did the plants dry the entire soil mass to a degree approaching the 15 atmosphere percentage (6.2) which is within the wilting range. By observation of plant response and soil moisture percentages it was found that the plants wilted by mid-morning when the average moisture content of the entire soil mass was reduced to the following approximate figures:

| Treatment, p.p.m. NaCl | Average moisture, % |
|---|---|
| 0 | 7.5 |
| 1,000 | 9.0 |
| 2,000 | 9.5 |
| 4,000 | 10.0 |

At this time the tensiometer readings at the 4-inch depth in all soil treatments were "off scale"[6] and in the "O" NaCl group the tensiometers at the bottom of the drum were also off scale.

When the beans were fully matured (April 8, 1942), the fruits were picked, weighed, counted, and photographed. The soil was sampled by taking portions from each third of the container according to depth. The top third was designated

[5]Tension or negative pressure is here measured by the height of the column of mercury or water which it supports.

[6]Tensiometer readings much above 800 cm of $H_2O$ are not considered accurate and the scale used to measure tensions is not graduated past 850. Further, the water column between the porous cup and the mercury manometer usually breaks near this latter tension range.

as 1/3, the middle third as 2/3, and the bottom third as 3/3. Specific electrical conductance determinations were made on the saturated soil paste from these samples.

## RESULTS

Differences in treatment resulted in differences in the growth response of the plants and modifications in the physical and chemical characteristics of the soil. Trends in plant growth differences were evidenced early in the experiment and became more marked with time.

Representative pots from each treatment at the time of maximum growth are shown in Fig. 1. Increased additions of sodium chloride to the soil progressively reduced plant growth. In pots having the same salt content, growth was greatest in the pots irrigated most fre-

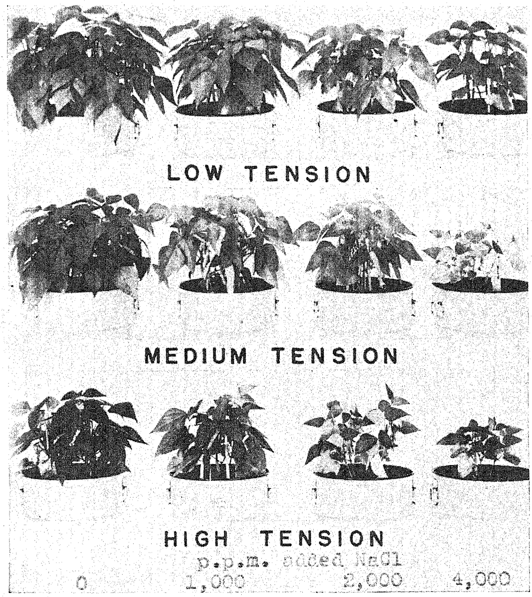


FIG. 1.—Growth of beans at four salt levels and irrigated at three soil moisture tensions.

quently and hence maintained at the lowest tension and was poorest in the pots receiving the fewest irrigations.

The plant responses to different treatments were reflected in fruit yields as well as in vegetative growth. The average number of pods, number of beans, and weight of the beans in grams per pot is given in Table 1. Actual beans harvested from the triplicate pots are shown in Fig. 2.

Table 2 presents the F values for the various sources of induced

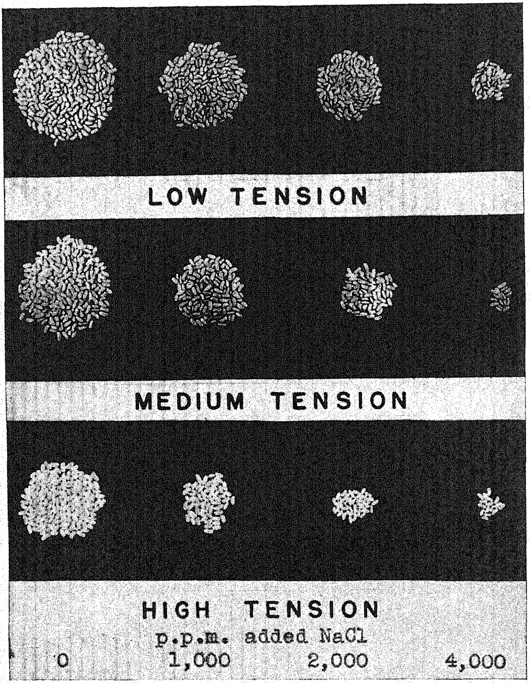


FIG. 2.—Yield of beans grown at four salt levels and irrigated at three soil moisture tensions.

variations upon the yield of beans per pot as well as the standard error and coefficient of variation.

TABLE 1.—*Average yield of beans per pot.*

| Added NaCl, p.p.m. | Tension at time of irrigation | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Low | | | Medium | | | High | | |
| | No. of pods | No. of beans | Grams of beans | No. of pods | No. of beans | Grams of beans | No. of pods | No. of beans | Grams of beans |
| 0 | 38.7 | 164.0 | 81.2 | 29.7 | 116.3 | 59.5 | 18.0 | 59.0 | 33.2 |
| 1,000 | 23.0 | 84.0 | 36.6 | 15.0 | 50.7 | 24.4 | 7.7 | 20.0 | 9.9 |
| 2,000 | 14.0 | 50.0 | 20.0 | 9.0 | 28.7 | 12.2 | 5.7 | 12.7 | 4.2 |
| 4,000 | 6.7 | 16.0 | 5.6 | 4.0 | 5.7 | 2.0 | 3.3 | 5.3 | 1.8 |

TABLE 2.—*F values for weight of beans per pot.**

| | |
|---|---|
| $T_1$ low tension – high tension | 384.25** |
| $T_2$ low tension + high tension – 2 medium tension | 0.18 |
| $S_1$ 0 NaCl – 1,000 NaCl | 612.13** |
| $S_2$ 2,000 NaCl – 4,000 NaCl | 42.50** |
| $S_3$ (0 + 1,000 NaCl) – (2,000 NaCl + 4,000 NaCl) | 1142.83** |
| $T_1S_1$ | 39.17** |
| $T_1S_2$ | 12.47** |
| $T_1S_3$ | 130.99** |
| $T_2S_1$ | 0.16 |
| $T_2S_2$ | 0.35 |
| $T_2S_3$ | 1.42 |
| Standard error | 0.627 |
| Coefficient of variation | 12.14% |

*Induced effects were segregated according to a single degree of freedom analysis (22). A chi square test of individual error terms indicated their homogeniety and the validity of using a pooled error term.
**Highly significant.

Distribution of the salts within the potted soils at the end of the experiment is indicated by specific electrical conductance measurements made on the saturated soil paste. These measurements are summarized graphically in Fig. 3.

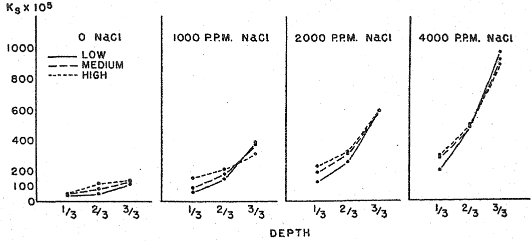


FIG. 3.—Conductance of saturated soil paste at 25° C.

Effect of treatment upon rate of growth and characteristics of fruit produced will be covered in a separate paper.

## DISCUSSION

### PLANT GROWTH IN THE "O" NaCl SERIES

As indicated in Figs. 1 and 2 and Table 1, the best growth and the highest yield of bean seeds were obtained in those containers which were maintained at low soil moisture tensions and to which no sodium chloride had been added. This treatment produced an average of 81 grams of beans per culture. Under the conditions of the medium moisture tension schedule, the vines produced an average of but 59 grams of beans per pot. This yield reduction occurred, although the plants were never wilted and there was always available moisture present. When irrigation was withheld from the plants until wilting[7] at mid-morning was in evidence (high moisture tension schedule), growth and yield were still further reduced. Under these conditions, each culture produced an average of only 33 grams of beans. The precision of this experiment was such (Table 2) that the above yield differences were well beyond the range required for high significance. Furthermore, the yield obtained from the medium tension pots was not significantly different from the mean of the low and high tension treatments. This is shown in Table 2 by the lack of a significant value for $T_2$.

The differences in yield obtained with the three irrigation schedules cannot be explained on the basis of root distribution. At the close of the experiment, examination showed that roots were well distributed throughout the entire soil mass in the "O" NaCl series. Increasing tensiometer readings also indicated that water was being removed from the lower depths as well as from the upper portions during the course of the experiment.

These reductions in the growth and yield of beans as the soils were allowed to dry to higher soil moisture tensions before being rewetted are in accord with the recent work of Davis (4) on nut grass. Previously, Furr and Taylor (7) and Aldrich, *et al.* (1) showed that with decreasing soil moisture the growth rate of lemon and pear fruits was retarded before the average soil moisture content reached the wilting range. Schneider and Childers (19) observed marked reductions in apparent photosynthesis and transpiration and an increase in respiration before wilting was evident in young apple leaves.

On the other hand, Veihmeyer (21), Conrad and Veihmeyer (3), and Hendricks and Veihmeyer (11, 12) found no decrease in plant growth under the conditions of their experiments as long as the soil was above the wilting point. Conrad and Veihmeyer (3) held that

[7]It is more difficult to describe the wilting of beans than of many common plants. The leaves of succulent plants with adequate water supply but suddenly subjected to a high transpirational stress will droop markedly in the conventional manner. However, plants which are gradually subjected to water stress respond by orienting their leaves parallel to the sun's rays and by inversion of the leaves. Actual drooping is not prevalent except on some of the oldest leaves. This latter type of response by the plant is referred to in this paper as "evidence of wilting".

even though the greater amount of roots or absorbing surface was in the top dry layers, roots in the deeper layers could absorb enough moisture to satisfy the needs of the plant, except under conditions of high evaporation.

In studying the daily growth of maize, Loomis (14) observed that direct sunlight inhibited the extension of the young leaf and attributed this to a temporary water stress brought about within the plant by the sunlight. A comparison of the leaf extension of a plant growing in moist soil and one growing in a relatively dry soil but still above the permanent wilting percentage, pointed to a higher average growth rate and longer growing period under the moist condition. Loomis found that the plant in the drier soil did not grow during the afternoon but did grow during the night. Apparently the growth of maize depends upon a liberal supply of water in the growing region. Sunlight, low relative humidity, and low soil moisture may check this growth by creating a moisture stress within the plant. This same sort of mechanism may influence the growth of beans and other plants.

When plants are unable to exert forces of sufficient magnitude to get water from the soil at a rate necessary to satisfy their needs, the plants wilt and death may be the final result. During this drying out process of the soil, the osmotic concentration of the plant sap increases (8, 13). This increase in the osmotic concentration of the plant sap, the decreased growth rate of lemon (7) and pear (1) fruits, and the reduction in photosynthesis and transpiration in apple leaves (19) as the soil moisture approaches but is not yet within the wilting range, indicate that increased water stresses are occurring within the plant as the soils become progressively drier.

A group of plants growing in moderately or partly dry soil will be under some water stress and, according to Loomis' theory, should have their growth retarded during periods of direct sunlight. Similar plants growing in moist soil should have less of an initial moisture stress and should therefore have shorter and less frequent periods of reduced growth and a faster growth rate. Other things being equal, the group of plants having the longest periods of actual growth and the highest rate should make the most growth. This reasoning could account for differences in growth between the low and medium moisture tension series.

## PLANT GROWTH IN THE 1,000, 2,000, AND 4,000 P.P.M. NaCl SERIES

Presence of added amounts of NaCl in the soil reduced growth. This was shown in Figs. 1 and 2 and Tables 1 and 2. F values for $S_1$, $S_2$, and $S_3$ indicate the reductions in the weight of beans produced to be highly significant. If the bean yield in the best treatment, no added NaCl at low soil moisture tension, is taken as 100 and if the other yields are plotted as a percentage of this figure, total relative yields are obtained as shown in Fig. 4. Besides the effect of NaCl, this graph demonstrates the relationship between yield and soil moisture tension at time of irrigation under the conditions of this experiment.

Breazeale (2), Eaton (6), Magistad, *et al.* (15), and others have correlated plant growth in culture solutions with the excessive con-

centration of salts in the solution. The concentration of salts in the soil solution in contact with and surrounding the plant roots plays a similar role in the soil. Breazeale (2) recognized this when he suggested that salts in the soil should be reported on the basis of the moisture content of the soil at the wilting point rather than as a percentage of the dry weight of the soil. Conductivity measurements of the saturated soil (Fig. 3) give a relative measure of the expected concentrations of these soil solutions. The actual magnitude of these concentrations for several selected samples is shown in Table 3, together with the calculated changes occurring in concentration as the soil dries from a percentage slightly above the "field capacity" to a point where plants in the nonsaline soil begin to wilt. Solutions were extracted from these soils at approximately 12% moisture by the

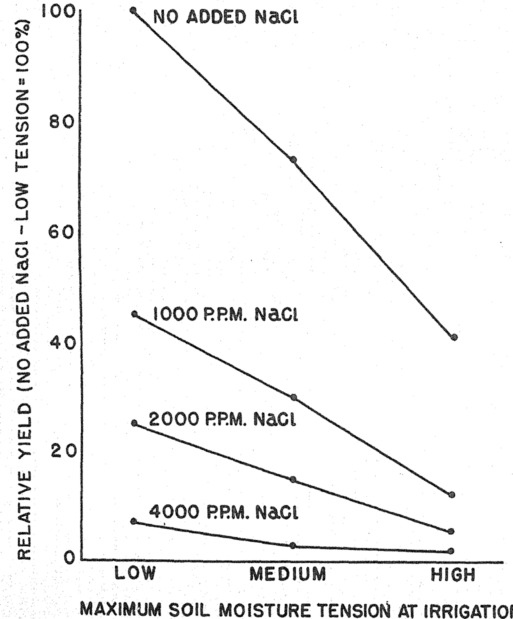


FIG. 4.—Relative yield of bean plants as conditioned by the various experimental treatments.

TABLE 3.—*Concentration of soil solution at close of experiment.*

| Added NaCl, p.p.m.* | Depth, inches | Conductance soil paste, $K_s \times 10^5$@25°C† | Soil moisture, % | Conductance soil solution, $K \times 10^5$@25°C | Concentration soil solution, atmosphere‡ | Calculated concentration of soil solution at four soil moisture percentages, atmos.§ | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 7% | 11% | 15% | 20% |
| 0 | 0–5 | 51 | 11.27 | 284 | 1.04 | 1.67 | 1.07 | 0.78 | 0.59 |
| 0 | 5–10 | 86 | 11.35 | 630 | 2.63 | 4.26 | 2.71 | 1.99 | 1.49 |
| 0 | 10–15 | 122 | 11.02 | 1,075 | 3.55 | 5.59 | 3.56 | 2.61 | 1.96 |
| 1,000 | 0–5 | 92 | 11.71 | 711 | 2.64 | 4.41 | 2.81 | 2.06 | 1.55 |
| 1,000 | 5–10 | 199 | 12.56 | 1,800 | 7.00 | 12.6 | 7.99 | 5.86 | 4.40 |
| 1,000 | 10–15 | 369 | 12.57 | 3,480 | 14.3 | 25.7 | 16.3 | 12.0 | 8.99 |
| 2,000 | 0–5 | 165 | 12.84 | 1,405 | 5.34 | 9.80 | 6.23 | 4.57 | 3.43 |
| 2,000 | 5–10 | 305 | 12.96 | 2,840 | 11.08 | 20.5 | 13.1 | 9.57 | 7.18 |
| 2,000 | 10–15 | 574 | 12.82 | 5,540 | 23.31 | 42.7 | 27.2 | 19.9 | 14.9 |
| 4,000 | 0–5 | 271 | 11.64 | 2,560 | 11.3 | 18.8 | 12.0 | 8.77 | 6.58 |
| 4,000 | 5–10 | 494 | 11.98 | 4,260 | 19.9 | 34.0 | 21.7 | 15.9 | 11.9 |
| 4,000 | 10–15 | 915 | 11.94 | 8,590 | 50.4 | 86.0 | 54.7 | 40.1 | 30.1 |

*All samples from medium tension series.
†Saturated soil paste contained 37% moisture.
‡Osmotic concentration of solution in atmospheres calculated from freezing point depression.
§Values calculated assuming only simple dilution or concentration.

pressure-membrane apparatus described by Richards (16) and concentrations at the other moisture contents calculated. Obviously, there is a tremendous change in concentration as the soils dry.

In order to show the effect of the moisture treatment in the presence of salts, the bean yields were recalculated on a relative basis using the yield of the low moisture tension treatment for each salt level as 100. Averages of the three replications are plotted in Fig. 5. The slopes of these curves show that when salts were present in the soil, increasing the soil moisture tension at the time of irrigation increased the severity of the salt treatment.

The reasoning that growth differences in soils at several moisture contents above the permanent wilting percentage may be due to

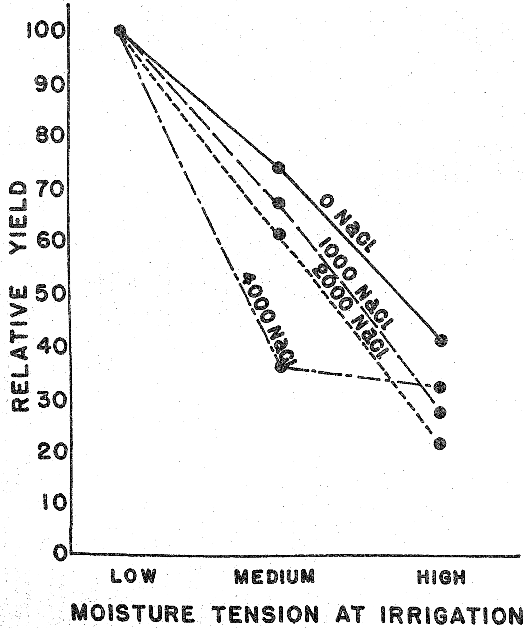


FIG. 5.—Relative yield of beans grown at four salt levels and irrigated at three soil moisture tensions using the yield at the low moisture tension at each salt level as 100.

water stresses affecting the total time and rate of actual growth is also applicable to the growth of plants in soils containing added NaCl. Decreased relative yields in the saline soils irrigated at increasing soil moisture tensions may be a reflection of the water stresses produced in the plant under these conditions.

### OSMOTIC EFFECT OF SOIL SOLUTION

With respect to the energy relations, more work is required to remove a gram of water from a solution as its concentration increases. Plants growing in saline soils must then do more work to obtain a given amount of water than plants growing in a less concentrated soil solution. Moisture treatments will affect the concentration of this soil solution. As shown in Table 3, soils which are allowed to dry to a point just above the wilting range will have for considerable periods of time a much more concentrated soil solution than similar soils which are kept relatively moist. In substantiation of the osmotic effect of the soil solution, Eaton (5) has brought out the fact that roots absorb more water from dilute than from the more concentrated solutions.

It is noteworthy that the soil to which no sodium chloride had been added revealed very significant osmotic concentrations of the soil solution. These concentrations arose mainly from the moderately heavy application of fertilizing materials. In the cultures in which the moisture content of the soil became low, it is evident that the concentration of the soil solution was sufficient to be definitely inhibitive to the growth of beans (15). This situation was unquestionably involved in the growth decreases accompanying the increased degree of soil moisture depletion prior to irrigation. Nevertheless, it should be emphasized that the yield of the plants in the cultures with 1,000 p.p.m. of added salt in the low tension series was higher than that from the "no salt" cultures of high tension series, even though the osmotic concentrations of these soil solutions within their respective limits of soil moisture content was just the reverse. This is shown as follows:

| | High tension, no salt | Low tension, 1,000 p.p.m. salt |
|---|---|---|
| Grams of beans | 33.2 | 36.6 |
| Osmotic concentration of soil solution at: | | |
| 0–5 in. | 1.67 | 2.06 |
| 5–10 in. | 4.26 | 5.86 |
| 10–15 in. | 5.59 | 12.0 |

The above observations suggest that far more attention should be given to osmotic relationship of soil solutions in non-saline as well as in saline soils. It would seem that particular study should be made of osmotic concentrations occurring when large fertilizer applications are made to heavy soils, and of the effect of such conditions on plant growth, apart from the plant food effect.

## EXTENSION OF ROOTS INTO NEW SOIL AREAS

The inhibiting action of concentrated soil solutions upon the extension of the plant root system into new soil areas may be even more important than the direct osmotic effect upon water absorption. Movement of water from unsaturated moist soil into dry soil is extremely slow. If the roots do not grow into new soil masses, water absorption is limited to areas already occupied by these roots and this available moisture may be quickly utilized. In the case of annual plants and rapidly growing young perennials, the extension of the root system is imperative for continued vigorous growth from the standpoint of the rate of absorption of both water and nutrients.

Eaton (5) showed that concentrated salt solutions definitely retard root growth. Additions of NaCl to soil in this experiment limited root distribution. This was evidenced from excavations made at the conclusion of the experiment as shown in Table 4, and from soil moisture tension measurements made in the pot during the growth period.

TABLE 4.—*Approximate depth of root penetration in inches.*

| Added NaCl, p.p.m. | Soil moisture tension at time of irrigation | | |
|---|---|---|---|
| | Low | Medium | High |
| 0 | 15* | 15 | 15 |
| 1,000 | 12 | 11 | 10 |
| 2,000 | 9 | 8 | 8 |
| 4,000 | 8 | 7 | 6 |

*Total depth of soil 15 inches.

## DECREASED ABSORPTIVE CAPACITY OF ROOTS

High concentrations of salts in the soil solution which limit root growth may affect moisture absorption by plants in still another manner. Maximum moisture absorption occurs just back of the root tip in the area where elongation is taking place and secondary thickening has not yet started (10). Roots in concentrated salt solutions grow slowly (5), becoming quickly suberized and having little rapidly absorbing root area (5, 9). Any factor, such as moisture level or the addition of NaCl, which affects the concentration of the soil solution will affect the amount of new roots being produced. Other things being equal, plants with a high percentage of young, rapidly absorbing roots should be able to take up water at a faster rate than plants having an equal amount of older roots.

Many factors undoubtedly play important roles in the effect of salts upon growth of plants in soils. It is not intended that climate, leaching, aeration, soil structure, soil reaction, direct toxicity of specific ions, and other effects be overlooked or minimized; but consideration should also be given to the part played by moisture stresses within the plant and the soil-root relationships which may affect these stresses. Relationships which should not be overlooked include (a) the increased work necessary to obtain water from the soil as the

soil moisture tension increases; (b) the increased work necessary to obtain water from the soil solution as the osmotic concentration of the soil solution is increased; (c) the inability of the plant roots to grow into areas of undepleted soil moisture because of the presence of high concentrations of salts in these areas; and (d) the inability of the plant to produce new roots having a maximum absorptive capacity because of the presence of high concentrations of salts in the soil solution. Each of these factors may be affected directly or indirectly by the frequency of irrigation and may have a bearing upon irrigation practice in saline soils.

## SUMMARY

Dwarf red kidney beans were grown to maturity in 10-gallon containers filled with loam soil. These soils contained 0, 1,000, 2,000, and 4,000 p.p.m. of added sodium chloride on the dry soil basis. The 36 containers were divided into three moisture tension series. Water was added when the soil moisture tension at the 4-inch depth had reached 250 cm of water and 750 cm of water for the first two series, respectively. Water was added to the third series when the plants were wilted by mid-morning, corresponding to tensions exceeding 800 cm of water.

Bean growth and yield were reduced as the soil moisture tension at time of irrigation increased, even though in some of the treatments the soil moisture was always above the wilting range.

Progressive additions of sodium chloride to the soil caused progressive decreases in growth and yield of beans.

The relative effect of sodium chloride on the reduction in yield of bean fruits was greater in those treatments in which the soil moisture tensions were greater at the time of irrigation.

Attention is called to a consideration of moisture stresses within the plant in relation to growth and to certain factors which may affect these stresses.

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# GRASSES FERTILIZED WITH NITROGEN COMPARED WITH LEGUMES FOR HAY AND PASTURE[1]

B. A. Brown and R. I. Munsell[2]

WHEN the war ends, some of the products of the synthetic nitrogen factories may be available for purposes other than munitions. For some time this question has been under study by a joint committee of the American Society of Agronomy, the American Society for Horticultural Science, the Association of Land-Grant Colleges and Universities, the National Fertilizer Association, the Tennessee Valley Authority, and the U. S. Dept. of Agriculture. The general idea appears to be that if nitrogen in fertilizers should be relatively cheaper than before the war, it might be a good policy for farmers to increase their use of this important plant nutrient.

For many years, the Agronomy Department of the Storrs, Conn., Agricultural Experiment Station has had hundreds of plots on which the response of grasses to various rates and times of application of nitrogenous fertilizers has been determined. On the same field and during the same seasons, legumes and legume-grass mixtures have been under test. It is the purpose of this paper to present the many data now available on these comparisons. All of the experiments were located at or near Storrs, on Charlton fine sandy loam soil, which, because of its compact subsoil, retains water relatively well and is therefore one of the best soil types in Connecticut for the growth of grasses.

## TIMOTHY FOR HAY

Timothy is the chief grass grown for hay in the hay-dairy belt of North America. Usually it is seeded with red clover, but after the second season, the clover is largely gone and the growth of the timothy is retarded for lack of nitrogen, unless topdressed with manure or nitrogenous fertilizers. To learn what changes in quantity and quality of hay could be obtained with nitrogen and different dates of cutting, a 1931 seeding of red clover and timothy was divided in 1933 into duplicated, 100×10 foot plots which were fertilized and mowed as outlined in Table 1. By 1938, the stand of timothy had become considerably mixed with other grasses, so the field was plowed and reseeded to timothy and a similar experiment continued through 1941. The pertinent results for the period of 1939–41 are presented in Table 2. For comparison, the yields of alfalfa from nearby plots and during the same years are included in Table 1 and yields of Ladino mixtures in Table 2.

It is apparent that the added nitrogen was responsible for marked increases in yields of both dry matter and protein from the timothy in the 5-year period 1933–37. If not cut *before June 15*, each of the two 28-pound increments of nitrogen enhanced the dry matter by 900 to 1,200 pounds. It will be noted, however, that the protein

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yields from the first cuttings remained practically constant for any given fertilizer treatment from June 1 to June 30. This was due to the declining percentage of protein with the increasing percentage of carbohydrates, as the timothy became more mature. Fiber increased from about 22 to 32% during the month of June. Even where nitrogen at 56 pounds was applied, the grass in the first cutting had absorbed the maximum amount by June 1. Fertilizer nitrogen at either 28 or 56 pounds caused greater growth but did not raise the percentage of protein. In this respect, the date of cutting was very important, as may be judged by the fact that on June 1 the protein content was 12%; on June 15, 9%; and on June 30, 7%. Protein is emphasized, not because animal rations cannot be balanced economically with oil meals, etc., but because usually there is a close correlation between protein and several other animal nutrients which indicate improved quality, like fat (ether extract) and the essential minerals.

TABLE 1.—*The effects of nitrogen and dates of cutting on the yields of timothy, 1933–37.**.

| Nitrogen applied, pounds per acre† | First cutting on | | | Second cutting following first cutting on | | | Totals if first cutting on | | |
|---|---|---|---|---|---|---|---|---|---|
| | June 1 | June 15 | June 30 | June 1 | June 15 | June 30 | June 1 | June 15 | June 30 |
| | | | | Dry Matter, Cwts. per Acre | | | | | |
| None | 10 | 16 | 23 | 8 | 4 | 4 | 18 | 20 | 27 |
| 28 in April | 20 | 29 | 35 | 7 | 4 | 3 | 27 | 33 | 38 |
| 28 in April; 28 in June | 20 | 31 | 35 | 16 | 9 | 5 | 36 | 40 | 40 |
| 56 in April | 25 | 39 | 46 | 6 | 5 | 4 | 31 | 44 | 50 |
| None; alfalfa, 2 cuttings in medium bloom stage | — | — | — | — | — | — | — | 56 | — |
| | | | | Protein, Pounds per Acre | | | | | |
| None | 128 | 161 | 181 | 88 | 50 | 50 | 216 | 211 | 231 |
| 28 in April | 248 | 240 | 237 | 85 | 48 | 46 | 333 | 288 | 283 |
| 28 in April, 28 in June | 242 | 271 | 228 | 127 | 111 | 74 | 388 | 383 | 302 |
| 56 in April | 341 | 348 | 335 | 74 | 62 | 59 | 414 | 410 | 394 |
| None; alfalfa, 2 cuttings in medium bloom stage | — | — | — | — | — | — | — | 840‡ | — |

*At Storrs timothy is in bloom the last part of June. The dates of second cuttings varied in some years; not in others.
†June N was applied *after* the first cutting.
‡The alfalfa was not analyzed in those years, so used one of the lowest percentages (15%) ever found in alfalfa at Storrs for calculating the yield of protein.

When June 15 was the date of first cutting and a second application of nitrogen was added soon afterwards, a *total* yield of fair weight and quality was obtained. This system produced 4,000 pounds of dry matter and nearly 400 pounds of protein. An additional 1,000 pounds of dry matter but no more protein resulted from applying 56 pounds of nitrogen in April and postponing the first cutting to June 30. In the same seasons, however, alfalfa cut two times per season and not fertilized at all after seeding, produced 40 and 12% more dry matter than the timothy cut first on June 15 and June 30, respectively, and

over twice as much protein as the timothy in *any* of the various fertilizer-cutting systems. It should be pointed out that the alfalfa in question was not analyzed and so one of the lowest percentages of protein every found in alfalfa at Storrs was used for the calculation of yield of protein. The lowest yield of protein from similarly cut alfalfa in another experiment during 1934 and 1935 was over 1,000 pounds per acre.

The 1939–41 results with the reseeded timothy are compared with the averages of five Ladino-grass mixtures, also seeded in 1938. This comparison is made because many farmers do not treat their soils and manage their crops so as to succeed with alfalfa. Ladino clover is a perennial legume that will thrive under soil conditions satisfactory for *good* results with timothy. For best results, however, Ladino-grass mixtures should be cut three times per season, at least. The data presented in Table 2 are from plots cut four times each year. The fourth, or October cutting, yields much less than the others and could be omitted or grazed without detracting greatly from the total production of hay.

TABLE 2.—*Comparison of timothy with Ladino-grass mixtures for hay, 1939–41.*

| Nitrogen applied, pounds per acre | Crops and cuttings | Total pounds per acre | |
|---|---|---|---|
| | | Dry matter | Protein |
| None | Timothy (first cut June 12) | 2,252 | 310 |
| 28 in April; 28 in June | Timothy (first cut June 12) | 3,643 | 371 |
| None | Timothy (first cut June 29) | 2,544 | 290 |
| 28 in April; 28 in June | Timothy (first cut June 29) | 4,337 | 324 |
| None | Averages of five Ladino-grass mixtures cut four times per year | 4,986 | 895 |

As may be seen in Table 2, nitrogen at 28 pounds in April and again in June increased the total dry matter yields of timothy about 1,400 pounds if the first cutting was June 12 and about 1,800 pounds if cut first on June 29. Because there was some volunteer white clover in the no-nitrogen plots, the use of fertilizer nitrogen resulted in only meager increases in the yield of protein. During the same seasons, the Ladino-grass mixtures averaged over one-third more dry matter than the timothy cut first on June 12 and one-sixth more than the timothy cut first on June 29. Moreover, the Ladino mixtures, with no fertilizer nitrogen, produced 141% more protein than the timothy to which was applied a total of 56 pounds of nitrogen each season.

## KENTUCKY BLUEGRASS AND RHODE ISLAND BENT GRASS FOR PASTURES

These two species are the chief grasses in improved permanent pastures of northeastern United States. In August, 1935, pure seed-

ings of each grass were made on adjacent 100×50 foot blocks. In the early spring of 1936, duplicate 50×8 foot plots on each block of grass were seeded to Ladino clover without tillage. During that and subsequent seasons, other plots of these grasses received nitrogen, chiefly in calnitro, at 28 pounds in each of the months of April, June, and August. All plots were lawnmowed 4 inches to 1 inch, an average of eight times per season for 7 years. The seasonal and total yields of dry matter and the average percentages of protein are shown in Table 3. It may be stated briefly that with either grass alone, the effects of nitrogen at 84 pounds per season were not equal in quantity or quality of pasturage to seeding Ladino clover with the grasses. The only advantage of the pure grasses plus nitrogen was that this system produced larger yields than the combination of grass and clover during the first two weeks in May.

TABLE 3.—*Grasses plus Ladino clover versus grasses plus fertilizer nitrogen for pasture.**

| Treatment | Dry matter, pounds per acre | | | | | | | Percentage protein† |
|---|---|---|---|---|---|---|---|---|
| | Before May 16 | May 16–June 15 | June 16–July 15 | July 16–Aug. 15 | Aug. 16–Sept. 15 | After Sept. 15 | Totals | |
| Rhode Island Bent Grass | | | | | | | | |
| Grass plus Ladino.. | 380 | 701 | 615 | 673 | 479 | 198 | 3,046 | 23.7 |
| Grass plus nitrogen. | 502 | 700 | 567 | 448 | 445 | 157 | 2,819 | 21.3 |
| Kentucky Bluegrass | | | | | | | | |
| Grass plus Ladino.. | 473 | 788 | 592 | 698 | 462 | 203 | 3,216 | 24.3 |
| Grass plus nitrogen. | 579 | 674 | 626 | 464 | 447 | 137 | 2,927 | 21.0 |

*Results are averages of 1936 to 1942 on plots, lawnmowed eight times per season. Grasses were seeded in August, 1935, and Ladino clover added in March, 1936. Nitrogen was applied to grasses alone at 28 pounds in April, June, and August, or a total of 84 pounds per year.

†Values given are average protein contents in 1937, 1938, and 1939. The crops were not analyzed in other years.

## NITROGEN ON PERMANENT PASTURES

The preceding discussion dealt with data obtained on tillable, seeded land, where it was possible to control to a considerable extent the species on the plots. For 10 years, 1932 to 1941, nitrogen was added at various dates and amounts to 7 of 17 2-acre, quantitatively grazed, permanent pastures. These pastures were grazed by yearling dairy heifers that received no supplemental feed. In Table 4 may be found a summary of the results.

All of the nitrogen plots produced larger *total* yields than the minerals plots. Most of the additional feed, due to nitrogen, grew in May and early June. This was especially true of the spring nitrogen plots. The least summer decline occurred on the pastures where nitrogen was withheld until June or August. The summer nitrogen, however, was much less effective in increasing growth than the spring treatments.

TABLE 4.—*Nitrogen and minerals versus minerals on permanent pastures.**

| Nitrogen applied, pounds per acre | | Total digestible nutrients, pounds per acre | | | |
|---|---|---|---|---|---|
| Rates and dates | Total per year | Before June 16 | June16–Aug. 15 | After Aug. 15 | Total |
| 28 in April | 28 | 832 | 426 | 296 | 1,554 |
| 28 in April and June | 56 | 957 | 511 | 328 | 1,796 |
| 28 in April, June, and August | 84 | 975 | 510 | 360 | 1,845 |
| 56 in April | 56 | 1,002 | 414 | 268 | 1,684 |
| 28 in June | 28 | 567 | 487 | 301 | 1,355 |
| 28 in August | 28 | 597 | 445 | 327 | 1,369 |
| 28 in June and August | 56 | 782 | 524 | 348 | 1,654 |
| Minerals only | 0 | 614 | 422 | 211 | 1,247 |

*Results from grazed plots 1932 to 1941. Clover occupied about 6% of the area in the N plots; 15% in those treated with minerals only.

In May and June grasses decrease so rapidly in palatability and feeding value that it is imperative to graze them to capacity during those months in order to keep the herbage in a leafy condition. In this experiment the spring nitrogen plots produced only 29% of the feed necessary for their May-early June load of stock during the remainder of the season. The corresponding values for the other groups were as follows: For the spring plus summer nitrogen group, 33%; for the minerals only pastures, 39%; and for the summer nitrogen plots, 47%. In other words, the use of spring-applied nitrogen on pastures increased the acreage of supplementary pastures or other feeds necessary to carry the same number of animals throughout the season.

On smooth land, surplus May-June pasturage can be mowed for hay or silage, but many of the permanent pastures in northeastern United States are too rough or steep for machine mowing. Moreover, on most farms in this region there is a far greater acreage of land suitable only for permanent pasture than there is for seeded pasture and other crops. Permanent pastures are probably the cheapest source of feed for cattle. These data would seem to demonstrate that the improvement of larger areas of permanent pastures by adding the necessary minerals is a far better practice than intensive fertilization with both minerals and nitrogen of a smaller area. Even on farms with pastures smooth enough to permit machine mowing of surplus May-June feed stimulated by spring nitrogen, it would seem to be a better practice to till and seed leguminous mixtures, which, as shown by the values in Tables 1, 2 and 3, will produce larger total and better distributed yields of forage than grasses receiving heavy applications of nitrogen. Moreover, if legumes are neither grazed nor mowed at a definite time, they do not depreciate in feeding value nearly so rapidly as the grasses.

## FERTILIZER NITROGEN ON LEGUMES

It has been stated by some that the nitrogen problem with forage crops is not a question of fertilizer nitrogen *or* legumes, but fertilizer

nitrogen *and* legumes. They suggest applying nitrogenous fertilizers to legumes as well as to grasses. The only data the Storrs Experiment Station has on this question are for nearly pure stands of alfalfa. With that crop, nitrate of soda applied at 125 pounds in April and repeated after the June cutting to 12 of 36 plots in 1934 and 1935 caused no significant differences in either protein content or yields of dry matter. Numerous tests with alfalfa have also shown that on well-limed and phosphated soils, the chief effect of stable manure is traceable to its content of potash. It has been observed many times that the heavy manuring of alfalfa resulted in severe lodging and the loss of most of the lower leaves.

In another experiment, the yields of some lawnmowed plots of turf grasses were not increased by applying nitrogen at 28 pounds in each of the months of April, June, and August when 40% or more of their areas were occupied by volunteer white clover.[3] In this case, as well as in other experiments at the Storrs Experiment Station, the nitrogen, chiefly from sulfate of ammonia, reduced markedly the prevalence of the clover and, of course, made it impossible to determine the yields of plots with both clover *and* fertilizer nitrogen.

## SUMMARY

The yields and quality of several grasses fertilized with nitrogen for hay and pasture are compared with those from legumes and legume-grass mixtures.

During a 5-year period, the yields of timothy were increased markedly by 28 or 56 pounds of nitrogen per acre annually, but in the same seasons alfalfa on nearby plots, unfertilized since seeding, produced more dry matter and over twice as much protein.

Ladino clover-orchard grass seedings also yielded more dry matter and much more protein than another stand of timothy fertilized with 28 pounds of nitrogen in each of the months of April and June.

The seeding of Ladino clover with either Kentucky bluegrass or Rhode Island bent grass, lawnmowed eight times per season for 7 years, resulted in slightly larger *total* and better distributed yields than the application of nitrogen at 28 pounds in each of the months of April, June, and August on the grasses alone.

On grazed permanent pastures, spring-applied nitrogen stimulated a 30% increase in *total* yields over mineral fertilization. Most of the additional growth occurred before June 16. Spring and summer nitrogen resulted in less May but more summer feed than from applying all of the nitrogen in April. The most uniform seasonal distribution of pasturage was obtained by adding nitrogen only in the summer, but the returns per unit of nitrogen were about half those from the spring treatments.

[3]Storrs (Conn.) Agr. Exp. Sta. Bul. 209. 1936.

# SOME EFFECTS OF THE WAXY GENE IN CORN ON PROPERTIES OF THE ENDOSPERM STARCH[1]

G. F. SPRAGUE, B. BRIMHALL, AND R. M. HIXON[2]

COLLINS (5)[3] and Kempton (9) have shown that the gene controlling waxy endosperm in maize is completely recessive to all other common types of endosperm, horny, flinty, pop, dent, starchy, etc., except the sugary type (6). When a plant having waxy kernels is crossed with a plant having starchy kernels, the hybrid kernels all have starchy endosperms regardless of whether the waxy plants are used as seed or pollen parent, and in the next generation segregation of the kernels occurs in agreement with the simple Mendelian ratio of 3 starchy to 1 waxy. The hard waxlike appearance of the waxy endosperm served as a ready means of identification in these experiments.

Parnell (10) reported similar observations with rice in which starchy is completely dominant over the waxy or glutinous condition. He differentiated the two kinds of kernels by their coloration with iodine, the former staining blue and the latter reddish-brown. The starch contained in the pollen grains exhibits the same color reaction with iodine as that contained in the endosperm. The pollen grains from homozygous starchy plants are blue-staining, those from waxy plants are red-staining, and those from a heterozygous plant are 50% blue-staining and 50% red-staining (4, 7, 10).

The present report deals with the properties of starches isolated from the endosperm genotypes Wx Wx Wx, Wx Wx wx, wx wx Wx, and wx wx wx, respectively, where Wx represents the starchy allel and wx the waxy allel. By the use of more sensitive criteria than endosperm texture or color with iodine, there was observed a distinct trend toward waxy properties in the starch as the proportion of waxy to starchy genes increased.

## EXPERIMENTAL METHODS

*Source of samples.*—The grain used in these studies was obtained from two hybrids, Iowa 939 and waxy 939. Iowa 939 was one of the first hybrids released by the Iowa Experiment Station and is homozygous starchy. The waxy 939 has been produced by introducing the waxy gene into four inbred lines of Iowa 939 (I205, L289, Os420, Os426) by means of the backcrossing technic. The waxy strains of the lines had been backcrossed for four to six generations when com-

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[3]Figures in parenthesis refer to "Literature Cited", p. 822.

bined, so the analogous lines I205Wx, I205wx, etc., should be largely isogenic. Using these two double crosses, four different endosperm genotypes were produced as follows:

1. Iowa 939, sib-pollinated .......................... WxWxWx
2. Iowa 939 × waxy 939 .......................... WxWxwx
3. Waxy 939 × Iowa 939 .......................... wxwxWx
4. Waxy 939, sib-pollinated .......................... wxwxwx

Each of these four lots of grain was a mixture of the grain from at least 25 ears.

*Milling.*—The four samples of corn were milled at the same time under identical conditions in a small-scale wet-milling unit, the operation of which has been described elsewhere (8). Two and one-half pounds of grain from each sample were placed in cheesecloth bags and the four samples steeped together at 50° C in 5 gallons of water which at no time contained more than 0.2% $SO_2$. This procedure assured that the variation in viscosity of the starches described below was not caused by any differences in the milling operation.

*Determination of amylose component present in the starch.*—This procedure has been described by Bates, French, and Rundle (1) in which 0.04 gram of starch is dispersed in 10 ml of 0.5 N KOH solution, diluted with 85 ml distilled water, and neutralized with hydriodic acid using methyl orange indicator. It is then titrated potentiometrically with a solution of 0.001 N iodine in 0.05 N KI. The iodine is added in 1-ml portions, allowing 2½ minutes after each addition before reading the voltage. The end-point of the titration is taken at the inflection point of the curve in which voltage is plotted against ml of iodine added. The significance of this measurement is pointed out below.

*Viscosity.*—Three grams of starch (dry basis) in 100 ml of distilled water were heated 35 minutes in a water bath at 90° C. Viscosity was measured at that temperature with a straight-form capillary Ostwald pipette, under pressures of 13 and 23 cm (2).

*Rigidity.*—Five grams of starch in 100 ml of water were heated on a water bath at 98° C for ½ hour and the pastes poured into rigidity cylinders and allowed to set to a gel overnight at room temperature. Rigidity was measured by the method of Brimhall and Hixon (3) and is a quantitative measure of the strength or elasticity of the gel.

## RESULTS

The differences in behavior between genetically pure non-waxy cornstarch, such as sample I, Table 1, with its high gelling properties and relatively low viscosity, and pure waxy cornstarch, sample IV, Table 1, with extremely high viscosity and almost no tendency to set to a gel, have been described in previous publications (3, 8). Viscosity and rigidity measurements, therefore, provide excellent, sensitive means of detecting differences in "degree of waxiness" among starches.

When pastes of each are made up on the water bath, a difference between pure non-waxy and sample III (wx wx Wx) is evident merely by visual observation. The latter is somewhat more translucent and contains a greater number of tiny bubbles, characteristics which are shown by waxy starch pastes to a high degree. Table 1 clearly illustrates the increase in viscosity and decrease in rigidity or gelling tendency of the starches as the number of waxy genes in the endosperm increases.

TABLE 1.—*The relation between endosperm genotype and rigidity and viscosity properties of the endosperm starch.*

| Starch No. | Genotype of endosperm | Rigidity Dynes/cm²×10⁻¹ | Viscosity in centipoises | |
|---|---|---|---|---|
| | | | 13 cm | 23 cm |
| I | WxWxWx | 222 | 24.4 | 16.5 |
| II | WxWxwx | 185 | 41.8 | 25.8 |
| III | wxwxWx | 61 | 66.6 | 33.4 |
| IV | wxwxwx | 0 | 490 | 230 |

An attempt was made, by mixing samples I and IV in known proportions, to get a paste approximating that of sample III in viscosity. It was found, however, that synthetic mixtures of non-waxy and waxy starch could not be made to duplicate the behavior of the starch milled from heterozygous wx wx Wx corn, since their viscosities decreased at different rates with increasing pressure, as shown in Fig. 1.

Another technic used to differentiate these starches, potentiometric titration with iodine, has a more sound theoretical basis than the

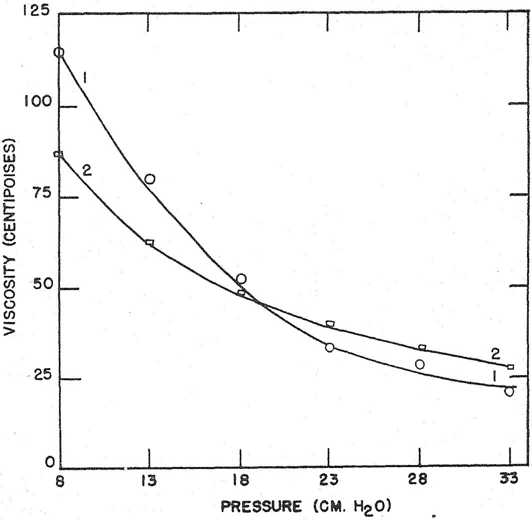


FIG. 1.—Viscosity-pressure curves for (1) non-waxy starch wxwxWx and (2) a mixture of 7 parts non-waxy with 1 part waxy starch. 3% pastes at 90° C.

foregoing methods. Most starches consist of two types of molecules, straight chain molecules, which make up the "amylose" fraction of starch and are responsible for its blue color with iodine, and branched molecules, which make up the "amylopectin" fraction and give only a red or red-brown iodine color. Ordinary cornstarch, like sample I, contains about 22% of the blue-staining constituent, or amylose, while waxy starch contains none at all, being 100% amylopectin.

Thus, all starches containing an appreciable amount of amylose will stain blue with iodine, and samples I, II, and III all appear to give the same blue color. However, by using a quantitative titration method like the above, differences can be detected easily, as shown in Fig. 2. Curves for samples II and III lie between those for pure non-waxy and pure waxy. In Table 2 are listed the relative percentages of amylose in the four samples as calculated from the curves in

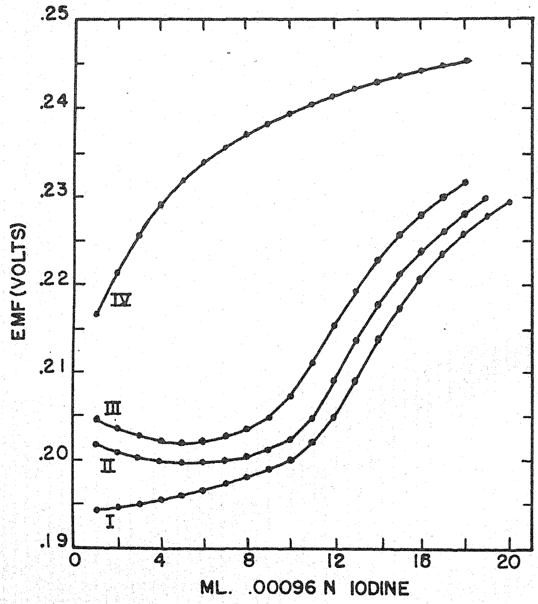


FIG. 2—Potentiometric titration curves for 0.04% solutions of starches. I, WxWxWx: II, WxWxwx; III, wxwxWx; IV, wxwxwx.

Fig. 2, along with the percentage of waxy starch which would have to be mixed with non-waxy starch to give identical titration curves.

TABLE 2.—*The relation between endosperm genotype and the percentage amylose of the endosperm starch.*

| Sample No. | ml. 0.00096N iodine | Amylose in sample, % | Waxy required, % |
|---|---|---|---|
| I | 13.75 | 22.0 | 0 |
| II | 12.75 | 20.4 | 7 |
| III | 11.50 | 18.4 | 16 |
| IV | 0 | 0 | 100 |

## DISCUSSION

Although preliminary in nature, the foregoing results indicate that the waxy gene is not completely recessive in its influence as was previously believed. This is evidenced by the intermediate properties of the two heterozygous types, Wx Wx wx and wx wx Wx. Ignoring the completely recessive type, wx wx wx, the data on rigidity and viscosity indicate a simple additive type of factor action. The data on percentage amylose indicate a rather high degree of dominance.

The fact that it is possible to produce starches of intermediate character is not of immediate industrial value because of the additional expense which would be involved. For example, if it were desirable to produce a starch having viscosity and rigidity properties of the Wx Wx wx type, it would be necessary to produce the grain for milling in a detasseled crossing plat rather than in a regular commercial field.

The results promise to be of considerable theoretical interest, however, in studying the mechanism of starch synthesis in the kernel. They may provide an approach to the question of how the waxy allel promotes synthesis of starch made up entirely of branched molecules, while the starchy allel promotes synthesis of starch containing a mixture of straight and branched molecules.

## SUMMARY

1. Starches were milled from corns having the following endosperm genotypes: Wx Wx Wx, Wx Wx wx, wx wx Wx, and wx wx wx, where Wx represents the gene for starchy and wx the gene for waxy endosperm.

2. As the ratio of waxy to starchy genes increased, the tendency toward waxy character in the starches also increased. The starchy genotype wx wx Wx corresponded in composition to a mixture of approximately 6 parts of non-waxy with 1 part of waxy starch.

3. Previous studies which established the complete dominance of the starchy gene used endosperm texture or iodine color to distinguish waxy from starchy corn. The use of more sensitive quantitative measurements as described in this paper, *viz.*, viscosity, gel strength, and potentiometric iodine titration, shows a definite waxy trend in starches from the genotype Wx Wx wx to that of wx wx Wx, both

of which by the older methods appeared identical with Wx Wx Wx starches.

4. The effect of the Wx allel appears to be additive in its action upon the viscosity and rigidity of the starch pastes and largely dominant with respect to its effect on the percentage of amylose present in the starch.

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# FLAX VARIETIES REGISTERED, I[1]

A. C. ARNY[2]

THESE are the first two flax varieties to be approved for registration. Biwing and Redson are selections from the cross Bison × Redwing made in 1929 at University Farm, St. Paul, Minn. The object in making the cross was to combine in new varieties the vigorous plant type, the moderately large seed size, the high oil percentage of the seed, and the high resistance to wilt, *Fusarium lini*, of the Bison parent with the high oil quality and the somewhat lower average rust infection, *Melampsora lini*, of the Redwing parent. Both parents had shown high yielding ability.

## BIWING, REG. No. 1

The summarized data given in Table 1 for the rod-row tests covering the period 1936–42 show that Biwing averaged significantly higher in yield than Bison at St. Paul, Waseca, and Morris and equalled Bison in yield at Crookston. The average yield for all the tests is significantly higher for Biwing than for Bison. In the 1/40-acre plot tests, Biwing yielded at a significantly higher rate than Bison at Waseca. At St. Paul, Morris, and Crookston the yields

TABLE 1.—*Yields in bushels per acre of Biwing and Redson in comparison with those of Redwing and Bison.*

| Variety | C. I. No. | St. Paul | Waseca | Morris | Crookston | Average |
|---|---|---|---|---|---|---|
| | | | Rod-row Tests, 1936–42 | | | |
| Redwing.... | 320 | 15.7 | 18.8 | 16.5* | 12.2† | 15.8 |
| Bison....... | 389 | 10.7 | 15.9 | 12.9 | 13.4 | 13.0 |
| Biwing...... | 917 | 14.2 | 18.5 | 16.9 | 13.2 | 15.6 |
| Redson..... | 970 | 14.2 | 18.4 | 16.9 | 13.3 | 15.6 |
| Sig. dif...... | | 1.65 | 1.84 | 1.45 | 1.61 | 0.82 |
| | | | Fortieth Acre Plot Tests, 1941–42 | | | |
| Redwing.... | 320 | 17.7 | 24.4 | 19.7 | 6.7‡ | 18.5 |
| Bison....... | 389 | 13.3 | 20.6 | 19.1 | 9.5 | 16.5 |
| Biwing...... | 917 | 16.2 | 23.7 | 19.9 | 7.9 | 18.2 |
| Redson..... | 970 | 18.3 | 23.9 | 20.6 | 12.3 | 19.7 |
| Sig. dif...... | | 3.95 | 1.95 | 2.53 | 2.96 | 1.47 |

*No yield in 1939.
†No yields in 1939 and 1942.
‡Yield in 1942 only.

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[1]Registered under cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication May 12, 1943.

[2]Associate Agronomist, Division of Agronomy and Plant Genetics, Department of Agronomy, University of Minnesota, St. Paul, Minn. Member of committee on Varietal Standardization and Registration of the Society charged with the registration of flax varieties.

of Biwing and Bison were similar. The average yield for Biwing was significantly higher than that of Bison. In all of the tests, Biwing was similar to Redwing in yield.

The average data other than yield for all the tests given in Table 2 show that Biwing was similar to Redwing in height, wilt percentage, and rust infection, and approached Redwing closely in iodine number of its oil. In 1,000-seed weight, wilt percentage, and pasmo infection, *Phlyctaena linicola*, Biwing approached closely to Bison. In date of maturity, bushel weight, and oil percentage of the seed, Biwing was midway between its parents. Biwing has light blue flowers similar to those of Redwing.

TABLE 2.—*Additional comparative data for the four flax varieties, averages for all tests, 1938–42.*

| Variety | Height, inches | Date mature | 1,000 seed weight, grams | Bushel weight, pounds | Oil in seed, % | Iodine number of oil | Wilt av., 8 tests, % | Rust infection, av. 15 tests* | Pasmo infection, av. 9 tests* |
|---|---|---|---|---|---|---|---|---|---|
| Redwing... | 25 | July 31 | 4.4 | 54.5 | 35.7 | 183 | 23 | M− | M |
| Bison...... | 26 | Aug. 8 | 5.6 | 52.9 | 37.0 | 171 | 7 | H− | L |
| Biwing.... | 25 | Aug. 3 | 5.3 | 53.9 | 36.3 | 179 | 9 | M− | L+ |
| Redson.... | 25 | July 31 | 5.4 | 54.5 | 36.2 | 181 | 3 | M+ | L+ |

*L = light; M = moderate; H = heavy.

## REDSON, REG. No. 2

Redson averaged almost identical with Biwing in all yields in the rod-row tests at the four stations. Redson yielded significantly higher than its Bison parent in the tests at St. Paul, Waseca, and Morris and in the average for all locations. In the 1/40-acre plot tests in 1941–42, Redson yielded significantly higher than Bison in the tests at St. Paul, Waseca, and Crookston and in the average for all tests. In the 1942 test at Crookston, Redson yielded at a significantly higher rate than the other varieties. At the other three stations the yields of Redson were not significantly different from those of Redwing.

In the characters other than yield given in Table 2, Redson was similar to Redwing in height, maturity date, and bushel weight of the seed and approached closely to Redwing in iodine number of its oil. Redson approached closely to Bison in 1,000-seed weight, iodine number of its oil, and rust and pasmo infection and showed a somewhat lower percentage of wilt than Bison. In oil content of the seed Redson was intermediate between the two parents. Redson has dark blue flowers like those of Bison.

# REGISTRATION OF VARIETIES AND STRAINS OF SWEET CLOVER, I[1]

E. A. HOLLOWELL[2]

COMMERCIAL seed of both biennial white sweet clover (*Melilotus alba*) and biennial yellow sweet clover (*Melilotus officinalis*) have become a mixture of different types and strains varying widely in degree of adaptation and desirability for different locations and uses. A considerable quantity of seed sold as sweet clover is a mixture of biennial white sweet clover and biennial yellow sweet clover. When such seed is shipped in interstate commerce in order to comply with the Federal Seed Act, the percentage of each species must be given, if more than 5% is present, or the seed must be labeled sweet clover without species designation.

A large part of the total sweet clover seed crop of the United States is produced in the region of western Minnesota and eastern North Dakota and South Dakota. Seed from this region produces semi-dwarf, early maturing types of biennial white and common biennial yellow sweet clover adapted to the culture and harvesting methods of that section. Their use in the seed-consuming sections of the Corn Belt states, however, reduces the potentialities of the crop, as the need there is for late-maturing, rank-growing strains to increase the quantity of forage and length of the grazing season.

The identification and multiplication of improved varieties and strains of sweet clover are desirable in order to preserve and make available seed containing the superior characteristics of this crop. Due to the problems of volunteer seed, pollination, and lack of seed-identifying characteristics, certification by state crop improvement associations seems essential to maintain the inherent superior qualities of the improved strains and varieties. Sweet clover varieties were registered in 1942 for the first time and three varieties have been approved for registration.

## SPANISH, REG. No. 1

Spanish (P. I. 27, 465), a variety of *Melilotus alba* formerly called Madrid white, originated as an introduction through the Division of Plant Introduction and Exploration from the Madrid Botanical Garden, Madrid, Spain, in 1910. Early trials were limited and it was not until 1926 that it was widely distributed to state agricultural experiment stations.

Spanish, the progeny of bulked seed of the introduction, is biennial

[1]Registered under a cooperative agreement between the Bureau of Plant Industry, Soils, and Agricultural Engineering Agricultural Research Administration, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication May 12, 1943.

[2]Senior Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering Agricultural Research Administration, U. S. Dept. of Agriculture. Member of the 1941–42 committee on Varietal Standardization and Registration charged with the registration of sweet clover varieties.

in growth habit and is white flowered. Leaf, stipule, stem, and flower characteristics are similar to common biennial white sweet clover. When compared with plants of other species and varieties of biennial white sweet clover, the characteristics of the first year's growth are as follows: Early seedlings vigorous, medium height, upright, foliage somewhat resistant to fall frost though not so resistant as the biennial yellow variety, Madrid. The second year's growth is leafy, upright, medium in height and in maturity. Seed production is heavy and early enough to escape the drought hazard common to the summer months in the eastern part of the Great Plains states. General regions of adaptation are the Corn Belt, Great Plains, and the intermountain states. The value of the variety has been clearly shown by comparative plantings in nurseries and field plots for the past 15 years. Yield data and discussions of the characteristics are presented in Table 1 and elsewhere (2, 3, 4, 8, 9).[3]

## MADRID REG. No. 2

Madrid (P. I. 27, 474), a variety of *Melilotus officinalis* formerly called Madrid Yellow, originated as seed introduction through the Division of Plant Introduction and Exploration from the Madrid Botanical Garden, Madrid, Spain, in 1910. Similar to Spanish, it was not widely distributed to state agricultural experiment stations until 1926.

Madrid, the progeny of bulked seed of the introduction, is biennial in growth and yellow flowered. Leaf, stipule, stem, and flower characteristics are similar to those of common biennial yellow sweet clover. When compared with other varieties and strains of *Melilotus officinalis*, the first year's growth is characterized as follows: Exceptional early seedling vigor, medium height somewhat decumbent, foliage resistant to fall frost. The second year's growth is leafy, upright, of medium height, and slightly later in maturity. Seed production is heavy and of sufficient earliness to escape the hazard of drought common during the summer months in the Great Plains. Limited quantities of seed of Madrid sweet clover are available. Yield data and discussion of the characteristics of Madrid sweet clover are given in Table 1 and elsewhere (1, 2, 3, 4, 8, 9, 10).

## EVERGREEN, REG. No. 3

Evergreen is a variety of *Melilotus alba* originated from plant selections made by J. B. Park, Department of Agronomy, Ohio Agricultural Experiment Station, Columbus, Ohio. Twenty-two individual plant selections were made in 1924 from fields and from mature roadside plants. One of these fields included a volunteer stand from an outstanding commercial late strain from the Park farm, first sown at the Ohio State University in 1921. One hundred and twenty-five additional selections were made in 1926 and 50 more in 1928 all of which were grown in plant-to-row progeny tests. Pollination was partially controlled by removing undesirable rows or plants.

[3]Figures in parenthesis refer to "Literature Cited", p. 829.

TABLE 1.—*Comparative hay yields in tons per acre of Spanish, Madrid, and common seed of biennial white and biennial yellow sweet clovers at various points.**

| Variety | 1931 | 1932 | 1933 | 1934 | 1937 | 1938 | 1939 | Av. |
|---|---|---|---|---|---|---|---|---|
| Manhattan, Kans. | | | | | | | | |
| Spanish | 3.23 | 2.15 | 1.84 | 1.19 | 3.39 | 1.62 | 3.78 | 2.46 |
| Common biennial white | 3.07 | 1.81 | 1.25 | 0.95 | 2.65 | 1.98 | 3.89 | 2.23 |
| Madrid | 2.96 | 2.69 | 1.83 | 1.04 | 1.98 | 1.47 | 2.55 | 2.07 |
| Common biennial yellow | 2.06 | 0.99 | 1.08 | 0.87 | 2.08 | 1.55 | 2.07 | 1.53 |
| Hays, Kans. | | | | | | | | |
| Spanish | 1.04 | 2.43 | 0.47 | 0.74 | — | — | — | 1.17 |
| Common biennial white | 0.98 | 2.27 | 0.29 | 0.67 | — | — | — | 1.05 |
| Madrid | 1.01 | 2.11 | 0.32 | 1.16 | — | — | — | 1.15 |
| Common biennial yellow | 0.64 | 2.19 | 0.39 | 0.53 | — | — | — | 0.94 |

Columbus, Ohio

| | 1934 | 1935 | 1936 | 1937 | 1938 | 1939 | 1941 | 1942 | Av. %† |
|---|---|---|---|---|---|---|---|---|---|
| Spanish | — | — | — | — | 2.54 | — | 2.99 | 2.38 | 105 |
| Common biennial white | 2.38 | 3.30 | 2.68 | 3.70 | 2.06 | 1.89 | 2.89 | 2.64 | 100 |
| Madrid | — | — | — | — | 2.46 | — | 3.46 | 3.06 | 118 |
| Common biennial yellow | 2.62 | — | 2.56 | 2.56 | 2.23 | 1.95 | 3.35 | 2.44 | 99 |

Ames, Iowa

| | 5-year av. |
|---|---|
| Spanish | 3.40 |
| Common biennial white | 3.32 |
| Madrid | 2.95 |
| Grundy County | 2.61 |

Lincoln, Nebr.

| | Pasture‡ | | | Hay§ | | |
|---|---|---|---|---|---|---|
| | 1941 | 1942 | Av. | 1941 | 1942 | Av. |
| Spanish | 1.58 | 1.73 | 1.66 | 2.01 | 2.50 | 2.26 |
| Common biennial white | 1.08 | 1.59 | 1.34 | 1.64 | 2.14 | 1.89 |
| Madrid | 1.41 | 1.61 | 1.51 | 1.61 | 2.45 | 2.03 |
| Common biennial yellow | 1.09 | 1.50 | 1.30 | 1.34 | 1.89 | 1.62 |

*Principally from unpublished data supplied by cooperating state Agricultural Experiment Station.

†Based on common white as 100%.

‡Cut three to four times to stimulate grazing.

§Each year's hay yield is the average of one first-year cutting and the total of two second-year cuttings.

Twenty strains were selected in 1928 and seven of these were sown in plots in the spring of 1929. From all available material, 11 mass selections of similar growth and maturity characteristics were made in 1930 and were increased as Ohio Nos. 1 to 11 in 1931 and 1933.

Considerable roguing was done in 1932. Some of these strains were distributed to farmers for trial in 1933. In the spring of 1935, seven of these mass selections were composited under the name "Evergreen".

Evergreen is white flowered, biennial in growth habit, and its leaf, stipule, stem, and flower characteristics are similar to common biennial white sweet clover. When compared to common biennial white sweet clover, the first year's growth is tall, upright and some-

TABLE 2.—*Comparative hay yields in tons per acre of Evergreen compared with common biennial white and common biennial yellow sweet clovers at various points.**

| Variety | 1937 | 1938 | 1939 | 1940 | Av. |
|---|---|---|---|---|---|
| **Columbus, Ohio** | | | | | |
| Evergreen | 5.62 | 2.64 | 3.64 | — | 3.96 |
| Common biennial white | 3.72 | 1.90 | 2.89 | — | 2.84 |
| Common biennial yellow | 2.57 | 2.33 | 3.35 | — | 2.77 |

Ames, Iowa

| | |
|---|---|
| Evergreen | 4.54 (4 years) |
| Common biennial white | 3.32 (5 years) |
| Grundy County | 2.61 (5 years) |

Manhattan, Kans.

| | 1939 | | 1940 | | 1941 | | 1942 | | Average | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Hay, tons | Seed, bu. | Hay, tons | Seed, bu. | Hay, tons | Seed, bu. | Hay, tons | Seed, bu. | Hay, tons | Seed, bu. |
| Evergreen | 5.24 | 5.26 | 4.62 | 2.61 | 3.86 | 1.62 | 3.91 | 5.61 | 4.41 | 3.78 |
| Common biennial white | 3.88 | 11.42 | 3.75 | 5.55 | 2.40 | 5.22 | 3.00 | 6.65 | 3.24 | 7.21 |
| Common biennial yellow | 2.07 | 10.50 | 2.71 | 6.61 | 2.13 | 3.31 | 3.62 | 6.40 | 2.63 | 6.71 |

Lincoln, Nebr.

| | Average first and second year crops, tons | | | | | |
|---|---|---|---|---|---|---|
| | Pasture† | | | Hay‡ | | |
| | 1941 | 1942 | Av. | 1941 | 1942 | Av. |
| Evergreen | 1.66 | 2.10 | 1.88 | 2.24 | 3.25 | 2.75 |
| Common white | 1.08 | 1.59 | 1.34 | 1.64 | 2.14 | 1.89 |
| Common yellow | 1.09 | 1.50 | 1.30 | 1.34 | 1.89 | 1.62 |

*Principally from unpublished data supplied by cooperating state agricultural experiment stations.

†Cut three to four times to simulate grazing.

‡Each year's hay yield is the average of one first-year cutting and the total of two second-year cuttings.

what coarser. The second year's growth is tall, coarse, and 3 to 4 weeks later in maturity than common biennial white sweet clover. In Ohio it blooms over a long period and sets seed freely. The harvesting of large seed yields is difficult because the seed shatters, due to the rank growth characteristics and the long blooming period. In the eastern edge of the Great Plains states frequent periods of high temperatures and drought are conducive to low seed yields or seed failures. Evergreen is well adapted throughout the Corn Belt and the eastern edge of the Great Plains states. Yield records and discussions of its characteristics are given in Table 2 and elsewhere (2, 4, 5, 6, 7, 8, 9).

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# REGISTRATION OF VARIETIES AND STRAINS OF RED CLOVER, I[1]

E. A. HOLLOWELL[2]

IN 1928 the Bureau of Plant Industry of the U. S. Dept. of Agriculture, in cooperation with several state agricultural experiment stations, obtained approximately 75 lots of red clover seed, each of which had been grown on the same farm for a minimum of 10 years without any admixture of other seed. These were tested at three different places in the red clover belt. From these and other tests, three general regions (southern, central, and northern) of adaptation became evident, together with some of the factors that were important in each region (6).[3] While the old strains proved to be best adapted to the locality where produced, it was found that they could be moved latitudinally within limits of similar climatic factors without much loss in adaptation.

Concurrent experiments indicated that the red clover seed of the northwestern seed-producing states was not so satisfactory when used in the eastern seed-consuming states. Results of experiments also indicated that the growing of red clover varieties for successive generations in a location differing from the place of origin in factors affecting adaptation, reduced the productiveness of the variety when the progeny was planted in the original location.

Procedures and regulations pertaining to the maintenance of the superior characteristics of red clover varieties and strains have been developed and are given in the annual reports (7) of the International Crop Improvement Association. Certification of improved red clover varieties and strains is essential, since most of the varieties cannot be distinguished by seed or plant morphological characteristics. Red clover varieties and strains are being registered in 1942 for the first time and two varieties have been approved for registration.

## CUMBERLAND, REG. No. 1

Cumberland, formerly called Southern Disease Resistant Blend, originated in 1937 as a composite of equal proportions of three identified superior strains, Kentucky No. 101 or No. 215, Tennessee Anthracnose Resistant, and Virginia (Sanford). This variety, the result of 13 years of breeding, testing, and increasing, was developed through a cooperative program of the Kentucky, Tennessee, Virginia, Idaho, Montana, Washington, Utah, Colorado, and Oregon

[1]Registered under a cooperative agreement between the Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication May 12, 1943.

[2]Senior Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture. Member of the 1941–42 committee on Varietal Standardization and Registration charged with the registration of red clover varieties.

[3]Figures in parenthesis refer to "Literature Cited", p. 832.

agricultural experiment stations and crop or seed improvement associations, the International Crop Improvement Association, and the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture. Provision is made for the substitution of other strains equal or superior to those used in the original composite in order to maintain an adequate stock of foundation seed necessary in the program. The objectives of the development of Cumberland are presented elsewhere (4, 7).

Cumberland has good growth characteristics, is resistant to southern anthracnose and crown rot, and is adapted to the southern region of the principal red clover belt. Yield data and discussion of the characteristics of Cumberland red clover are given in Table 1 and elsewhere (1, 2, 3, 4, 7, 8).

Approximately 120,000 pounds of certified Cumberland seed were produced in the states of Montana, Idaho, Washington, Utah, and Oregon in 1942 for use in the eastern states. Sources of Cumberland seed are available through state crop or seed improvement associations.

## MIDLAND, REG. No. 2

Midland, formerly called Central Corn Belt Blend, originated as a composite of equal proportions of four old strains, Illinois (Rahn and Letcher), Ohio (Poland), Indiana (Otten), and Iowa (Emerson), in 1935. Due to drought conditions in 1930–36, the foundation seed stocks of the Indiana and Iowa strains were reduced to a few pounds and these have not been included in the composite for several years. These strains are being increased and as soon as sufficient seed is available they will be included in the composite. Provision is made for the substitution of other strains equal or superior to those used in the original composite in order to maintain an adequate stock of foundation seed necessary in the program. The more satisfactory Ohio (Kirch and VanFossen) strains have been substituted for the Ohio (Poland) strain. Midland, the result of 13 years of breeding, testing, and increasing, was developed through cooperative efforts of the Ohio, Indiana, Illinois, Iowa, Idaho, Washington, Utah, Oregon, Colorado, and Montana agricultural experiment stations and crop or seed improvement associations, the International Crop Improvement Association, and the Division of Forage Crops and Diseases, Bureau of Plant Industry, Agricultural Research Administration, U. S. Dept. of Agriculture. The objectives of the development of Midland are presented elsewhere (5, 7). The procedures and regulations pertaining to the handling and increasing of Midland to preserve the superior characteristics are given in the annual reports (7) of the International Crop Improvement Association.

Midland has good growth characteristics, is winterhardy, and has some resistance to northern anthracnose. As the name suggests, it is adapted to the middle or central part of the Corn Belt states. Yield data and discussion of the characteristics of Midland red clover are given in Table 1 and elsewhere (1, 2, 5, 7, 8, 9).

TABLE 1.—*Comparative hay yields of Cumberland and Midland compared with other strains and common red clover at various points.**

| Variety | 1935 | 1936 | 1937 | 1938 | 1939 | 1940 | 1941 | 1942 | Av. % based on Ohio as 100% |
|---|---|---|---|---|---|---|---|---|---|
| Lexington, Ky., yields on basis of Tennessee Anthracnose Resistant as 100% | | | | | | | | | |
| Cumberland | — | — | — | — | 100.6 | 100.3 | 106.4 | — | — |
| Midland | — | — | — | 88.3 | 65.9 | 99.7 | 96.7 | — | — |
| Idaho | — | — | — | — | — | — | 68.9 | — | — |
| Virginia | — | — | — | 94.9 | 91.8 | 112.1 | 119.6 | — | — |
| Kentucky | — | — | — | 106.3 | 101.6 | 114.6 | 115.7 | — | — |
| Arlington Farm, Rosslyn, Va., Tons per Acre | | | | | | | | | |
| Kentucky† | 2.83 | — | 3.62 | 2.27 | — | — | — | — | — |
| Virginia† | 2.52 | — | 3.18 | 1.95 | — | — | — | — | — |
| Tennessee† | 2.63 | — | 3.74 | 2.15 | — | — | — | — | — |
| Idaho | — | — | 2.73 | — | — | — | — | — | — |
| Oregon | 1.50 | — | — | — | — | — | — | — | — |
| Midland | — | — | 3.32 | 1.65 | — | — | — | — | — |
| Urbana, Ill., Tons per Acre | | | | | | | | | |
| N. Ohio | — | — | — | 3.88 | 2.08 | — | 1.22§ | — | — |
| Midland | — | — | — | 3.91 | 2.64 | — | — | — | — |
| Illinois | — | — | — | — | — | 3.17 | — | — | — |
| Midland‡ | — | — | — | — | — | 3.58 | 1.36§ | — | — |
| Ames, Iowa, Tons per Acre | | | | | | | | | |
| Midland | — | — | — | 3.29 | 2.32 | 3.24 | 2.50** | — | — |
| Oregon | — | — | — | — | — | 3.00 | 1.93** | — | — |
| Idaho | — | — | — | — | — | 3.15 | — | — | — |
| Iowa | — | — | — | 3.18‖ | 2.25 | — | 2.99†† | — | — |
| Columbus, Ohio, Tons per acre | | | | | | | | | |
| Ohio | — | 1.72 | 3.94 | 4.04 | 1.77 | — | 2.40 | — | 100 |
| Midland | — | 2.10 | 3.59 | 4.12 | 1.88 | — | 2.30 | — | 104‖ |
| Cumberland | — | — | — | — | 2.20 | — | 2.14 | — | 106 |

*Principally from unpublished data supplied by cooperating state agricultural experiment stations.
†Cumberland is composed of these strains.
‡Average of three lots.
§One cutting the second year.
‖Average of two strains.
**Average of two lots.
††Emerson strain.

Approximately 220,000 pounds of certified Midland seed are available for planting in the eastern states in 1943. Sources of seed may be obtained through state crop or seed improvement associations.

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# SOYBEAN VARIETY REGISTERED, I[1]

W. J. MORSE[2]

THE first variety of soybean for registration under a cooperative agreement between the Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the American Society of Agronomy was submitted by Dr. W. C. Etheridge of the Missouri Agricultural Experiment Station.

## BOONE, REG. No. 1

Boone is a pure line selection from P. I. 54563-3[3] made by the Missouri Agricultural Experiment Station at Columbia, Mo., in 1930. P. I. 54563-3 originated from a selection made by W. J. Morse in 1922 from P. I. 54563, received from Jungchiangko, Manchuria, in 1921.

The selected strain, now named Boone, first distributed in 1935, is commercially grown on a moderate scale in central and southern

TABLE 1.—*Annual and average acre yields in field plots of Boone and two standard varieties at Columbia, Mo., 1937–41, inclusive.*

| Variety | Yields in bushels per acre | | | | | |
|---|---|---|---|---|---|---|
| | 1937 | 1938 | 1939 | 1940 | 1941 | Average |
| Boone | 16.2 | 20.2 | 19.1 | 21.4 | 25.1 | 20.4 |
| Manchu | 12.0 | 19.7 | 18.0 | 22.7 | 19.8 | 18.4 |
| Illini | 11.0 | 20.9 | 14.0 | 15.9 | 17.2 | 15.8 |

TABLE 2.—*Three-, four-, and five-year average yields of Boone and four standard varieties for three Missouri stations.*

| Variety | Location and bushels of seed per acre | | |
|---|---|---|---|
| | Columbia, 4-yr. average | Elsberry, 3-yr. average | Sikeston, 5-yr. average |
| Boone | 21.0 | 24.8 | 23.8 |
| Scioto | 21.6 | 22.1 | — |
| Illini | 16.5 | 21.1 | 18.7 |
| Dunfield | 17.5 | 18.3 | 14.4 |
| Manchu | 19.5 | 20.1 | 18.1 |

[1]Registered under cooperative agreement between the Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication May 12, 1943.

[2]Senior Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, and member of the 1942–43 committee on Varietal Standardization and Registration charged with the registration of soybean varieties.

[3]P. I. refers to plant introduction number given by the Division of Plant Exploration and Introduction.

Missouri. It is grown under different names in various localities, most often as "Missouri Selection." It is generally well liked by farmers, particularly for upland soils of moderate fertility in central and southwestern Missouri. The most common objection to Boone is that its late maturity brings its harvest too late in the fall to be followed by timely seeding of wheat.

The variety has been thoroughly tested at eight different locations in the state, either on state experiment fields or in cooperation with farmers. The results obtained on experiment fields are given in Tables 1 and 2.

The following descriptive notes on the variety were submitted by Dr. W. C. Etheridge in the application for registration of Boone: Plants medium tall, determinate in growth habit; branches short; stalks medium coarse, standing well for harvest except on very rich land; pubescence gray; flowers white; pods mostly 2-seeded, resistant to shattering; seeds medium to small, straw yellow with light brown to pale hilum; oil, 19.91%; protein, 42.18%; maturity 125 to 130 days, or about the same as the Virginia variety.

## NOTE

### A TECHNIC FOR GROWING SEEDLINGS OF GRASS AND OTHER PLANTS FOR FIELD TRANSPLANTING

WHEN the seed supply for a field planting is limited, or when plantings of single, spaced plants are desired, a common practice has been to start the seedlings under favorable conditions in the greenhouse or hotbed and transplant them to the field. Such a procedure is particularly effective in the establishment of experimental plantings of many forage grasses when individual plants are to be studied. Low germination in some species and lack of seedling vigor in others result in considerable difficulty in securing uniform stands when single seeds are planted directly in the field.

None of the usual technics in seedling culture seem particularly suitable for handling large numbers of grass seedlings. Grass plants, for transplanting, cannot ordinarily be started in flats without partitions of some kind to keep the individual plants separated. The smallest available clay or fiber pots and wood veneer or paper bands were not considered practical for grass seedlings when thousands of plants must be grown each spring in limited greenhouse space and at a reasonable cost. A plant band method for handling seedlings of grass and other forage crops prior to their transfer to the field has been developed which may be of value to others engaged in crop improvement programs.

Tests were run with several kinds of paper made into bands of various sizes to determine the most suitable container for growing grass seedlings in the greenhouse for periods of 2 to 8 weeks. The aim was to develop a plant band (1) of the minimum dimensions necessary to produce a seedling of sufficient size to permit successful establishment under field conditions, (2) which need not be removed from the roots at the time of transplanting, (3) made from inexpensive and accessable material, and (4) which would keep the root systems of individual plants separate during the greenhouse growing period.

Types of paper tested included No. 10 asphalt building paper; plain, oiled, and paraffined, 50-pound kraft wrapping paper; and plain and paraffined newsprint paper. Plant bands 3¼ inches deep and ¾, 1, and 1½ inches square were made from these materials. The completed bands were set up in redwood flats and filled with a soil fertilized with either ammonium sulfate or a 4–12–4 commercial fertilizer. Investigations carried out by Youden and Zimmerman[1] and others have shown that in order to produce normal growth nitrogen must be added to the soil when seedlings are grown in fiber or paper containers.

Greenhouse and field trials showed that bands ¾ × ¾ × 3¼ inches made of untreated newsprint most nearly satisfied the requirements for grass seedlings. When filled with sandy loam soil to which commercial fertilizer had been added, these containers provided satisfactory conditions for growth of grass seedlings for at least 8

[1]YOUDEN, W. J., and ZIMMERMAN, P. W. Field trials with fiber pots. Contr. Boyce Thompson Inst., 8:317–331. 1936.

weeks under greenhouse conditions. Seedlings grown in the smaller bands were fully as large as those produced in the larger sizes. Furthermore, in an equal space, four times as many seedlings could be grown in $\frac{3}{4}$-inch as in $1\frac{1}{2}$-inch bands. Matting of roots on the bottoms of the flats occurred regardless of the size or kind of plant band. The root systems of the individual plants in the $\frac{3}{4}$-inch bands were, however, readily separated for transplanting. The photographs in Fig. 1 show grass seedlings 8 weeks old grown in $\frac{3}{4}$-inch newsprint bands.

In a dry-land planting made during the spring of 1941, in which 9,000 seedlings of a wide variety of grass species were set out, a survival of 94% was recorded in mid-summer. These seedlings had been started in the greenhouse in $\frac{3}{4}$-inch bands and were only 16 days old when transplanted. As good, and probably better, establishment could be expected from larger seedlings under the same conditions. The net cost per 100 plants was 37 cents for all processes involved in establishing the seedlings in the field, including setting up the bands, filling the flats with soil, planting the sprouted seeds in the bands, and transplanting to the field. This cost was figured on the basis of labor at 35 cents per hour. An added benefit, not shown in the cost, was the small amount of greenhouse space used for starting the seedlings. The 9,000 seedlings growing in newsprint bands in flats required a space of only $4 \times 12$ feet.

This seedling technic has also been used successfully with alfalfa and clovers. The method may be useful for any plants with which crowding would not occur while growing in the bands, or, when this factor would not be a limiting one in subsequent growth or survival of the seedlings in the field.

## SEEDLING TECHNIC

Sheets of common newsprint paper, $3\frac{1}{2} \times 3\frac{1}{4}$ inches, are obtained from a printing shop for a few cents per thousand. The bands are shaped by folding with pressure around a sharp-edged block of hardwood having dimensions of $\frac{3}{4} \times \frac{3}{4} \times 5$ inches (Fig. 2A), and placed between supports B and C (Fig. 2) while still wrapped around the block. The block is then removed and the band retains the desired shape. The sheets of newsprint are folded with the longer axis ($3\frac{1}{2}$ inches) at right angles to the block. When folded in this manner, there is an overlap of $\frac{1}{2}$ inch on the side of the band placed against support C. Vertical lines ruled on support B at $\frac{3}{4}$ inch intervals aid in proper spacing of the bands. As each row of bands is completed, support B is removed and inserted between the last row and support C. Support C is then removed and placed in the next slot forward in the cross-supports, D. While the first few rows of bands are being folded, the support E, placed near the center, holds the slotted cross-supports in position between the second and third bands from either end of the flat. The support E may be removed when enough rows of bands have been set up to hold the cross-supports in position. The supports D are removed when the flat is filled with bands. When completely filled, a flat having inside dimensions of $15 \times 22\frac{1}{2}$ inches (Fig. 2), contains 600, $\frac{3}{4}$-inch bands.

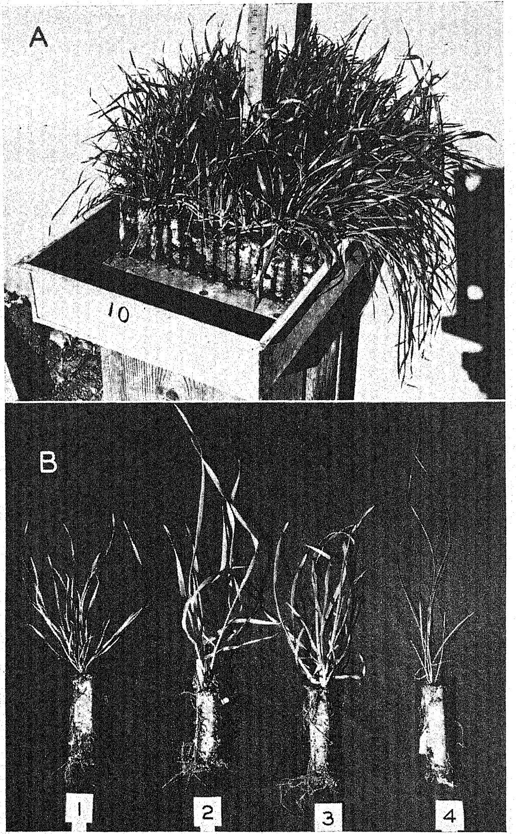


FIG. 1.—Appearance of grass seedlings grown for 8 weeks in ¾-inch newsprint bands. Individual seedlings in B were taken from the flat in A and are (1) *A. trachycaulum*, (2) *B. inermis*, (3) *D. glomerata*, and (4) *F. rubra*.

A redwood flat is shown in Fig. 2 partially filled with $\frac{3}{4}$-inch newsprint bands to illustrate the procedure of folding and placing the bands in position. By modifying the length dimensions of the supports, other shapes and sizes of flats may be used with these bands in a manner similar to that described. Little experience is required to set the bands up after the necessary supports have been made.

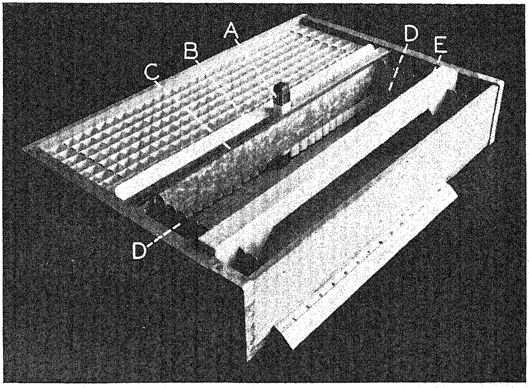


FIG. 2.—Greenhouse flat, $15\times22\frac{1}{2}\times3\frac{3}{4}$ inches inside, partially filled with $\frac{3}{4}$-inch newsprint bands. A, block, $\frac{3}{4}\times\frac{3}{4}\times5$ inches, with sharp metal edges; B and C, supports, $3\times22\frac{1}{4}$ inches, 28 gage galvanized iron with the upper $\frac{3}{4}$ inch bent at a $45^\circ$ angle; D, cross supports, $3\frac{3}{8}\times14\frac{3}{4}$ inches, 24 gage galvanized iron, and containing 19 slots, $\frac{1}{16}\times2\frac{3}{8}$ inches, spaced at $\frac{3}{4}$-inch intervals; E, support, $1\frac{1}{8}\times2\frac{3}{4}\times22\frac{1}{4}$ inches, with a vertical saw cut 2 inches deep $1\frac{1}{2}$ inches from either end; F, removable side.

Soil used in filling the newsprint bands must be dry and contain at least supplemental nitrogen. The most successful practice has been to mix 100 grams of a powdered, complete commercial fertilizer (Vigoro) having a 4–12–4 composition to each 5 gallons of screened soil before filling the bands. Failure to provide more nitrogen than is present in even a fertile soil results in a stunting of seedlings in a very short time. The bands are filled to the top and the excess soil scraped off. By tapping the bottom of the flat the soil will settle to about $\frac{1}{4}$ inch below the top of the bands. The soil in the bands is saturated with water immediately before seeds are planted.

Seedlings are started in the flats by placing a germinated seed in each band. Shallow trays or pot saucers filled with soil and saturated with water provide satisfactory containers for germinating the seeds. The seeds are placed on the surface of the soil and the saucers or

trays placed in a closed chamber until sprouts appear.[2] The germinated seeds are transferred with forceps to the water-saturated soil in the bands before the sprouts have reached a length of ¼ inch and covered with soil to a depth of ⅛ to ¼ inch. This planting procedure has usually resulted in a better than 95% stand of seedlings in the bands. Planting of sprouted seeds in the bands is more rapid than pricking off seedlings in the usual manner and, in addition, decreases the chance for the entrance of damping-off organisms into the seedlings via injured rootlets.

For transplanting, easy access to the plants is provided by removing one side of the flat (Fig. 2F). Transplanting is accomplished by dropping the column of soil and roots held intact by the band into a hole made by a dibble[3] of a slightly larger diameter than the band. Soil is firmed around the band and roots by applying pressure to one side of the hole with the heel of the foot placed 2 or 3 inches from the hole. A crew of four men has transplanted over 4,500 grass seedlings grown in ¾-inch newsprint bands in 8 hours following this procedure.—DEAN F. MCALISTER, *Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, Logan, Utah.*

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[2]Another convenient method of sprouting seeds has been to place seeds on the botton of an inverted, clay pot saucer which has previously been soaked in water. When covered with another saucer or placed in a moist atmosphere, the water supplied by the saucer is often sufficient to produce germination. Water may be added to the seeds from time to time with an atomizer or any device which will produce a fine spray.

[3]A very convenient dibble, which is operated from a standing position, consists of a 1¼-inch, round, iron pipe 5½ feet long with a closed, bluntly pointed lower end. A 5-inch collar welded in a position 3½ inches from the shoulder of the point regulates the depth of the hole. This tool was designed by Dr. John W. Carlson, Associate Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, Logan, Utah.

# BOOK REVIEWS

## THE NATURE AND PROPERTIES OF SOILS

*By T. Lyttleton Lyon and Harry O. Buckman. New York: The Macmillan Co. Ed. 4. XI+499 pages, illus. 1943. $3.50.*

THIS volume is the fourth edition of this well-known college text book. The revision made by Harry O. Buckman is thorough and complete. More emphasis of a technical nature is placed on the physics of soil moisture and the chemistry of the colloidal state than in preceding editions, but important subject matter has not been deleted. Soil conservation is considered in the broad sense and is discussed as an integral part of several topics as soil moisture, soil colloids, soil organic matter, fertilizers, and soil management.

The volume has excellent references to subject matter and contains a complete author and subject index. It is a valuable, timely, and up-to-date contribution. (R. I. T.)

## THE DIAGNOSIS OF MINERAL DEFICIENCIES IN PLANTS BY VISUAL SYMPTOMS: A COLOR ATLAS AND GUIDE

*By T. Wallace. London: H. M. Stationary Office. VI+116 pages, illus. in color. 1943. 10/-net.*

THIS publication by Doctor Wallace, the well-known worker at the University of Bristol Agricultural and Horticultural Research Station at Long Ashton, Bristol, is a contribution of the Agricultural Research Council of Great Britain.

The war has apparently created many new problems in British agriculture with its speeding-up program and the placing of a large acreage of grassland under the plow. This program has revealed many new mineral deficiencies in crops. Obviously, such deficiencies must first be recognized and diagnosed, so that this feature, based on changes produced in a selected series of indicator plants, is a main feature of the volume.

The 52 pages of text are aimed at laying a background and are concerned with the essential points in plant nutrition, relation of soils to mineral supply, methods of determining deficiencies, visual symptoms, a guide to symptoms in farm, garden, and fruit crops, and the use of the visual method in field diagnosis. The text also contains a considerable bibliography.

The remainder of the volume is taken up by 114 color photographs. Although the color reproduction in many cases is not all that might be desired, it is generally sufficiently good for the purpose intended. A valuable feature is the fact that some attempt at least is made to illustrate not only deficiency symptoms, but also results of excess concentration, normal senility changes in foliage, and insect and disease damage. It is unfortunate that these latter causes, which are many times so confusing in diagnosis, could not have been more fully presented. This, however, is a criticism which can be made of all the publications on this subject.

The volume is a valuable addition to "Hunger Signs in Crops" recently published by the National Fertilizer Association in this country.—(R. C. C.)

## MIRROR FOR AMERICANS: LIKENESS OF THE EASTERN SEABOARD, 1810

*By Ralph H. Brown. New York: American Geographical Society. Special Publication No. 27, XXXII+312 pages, illus. 1943. $4.00.*

ALTHOUGH primarily a geography, this is both a most informative and delightful book for the agronomist. It is more than a descriptive text of the physical geography of the eastern seaboard in 1810, or a careful compilation of the occupations of the people of that day based upon exhaustive research of authentic documents; it is indeed a mirrored reflection from the past showing a living generation going about its daily tasks. We catch glimpses of life on the plantations in the South, on the fringe of settlement in the Genesee Country, on the docks of Boston, on the fishing vessels headed for the Grand Banks, in the new cotton mills of Rhode Island, and on the post roads that extend westward.

Of special appeal to the agronomist are those parts of the books which give a picture of the agriculture of the period. Regional differences are clearly set forth; landscapes and local patterns of land use are brought out. The adaptations and distribution of the principal crops—corn, tobacco, wheat, cotton, rice, and indigo—are described together with accounts of cropping practices and farm management methods. This entire descriptive record of regional agriculture is based upon the papers and journals of eye-witnesses and excerpts have been effectively used and placed in the text to bring out detailed observations. Reference is also made to topics of debate, such as whether or not the climate is changing, and the role of such plants as clover, peas, and beans in the fertilization of worn-out soils.

The author states that the volume is intended as a short-cut to an understanding of American geography in 1810. The opening paragraph of the Preface, taken from Robert Rogers, famous leader of the Rangers, exemplifies the spirit of the book, although written under a different political situation. The quotation is as follows:

"It will not be expected, after volumes upon volumes that have been published concerning the Bri(t)ish colonies on the eastern shore of the American continent, that any thing materially new can be related of them. The only thing I mean to attempt with regard to this is, to collect such facts and circumstances, as, in a political and commercial view, appear to me to be most interesting; to reduce them to an easy and familiar method, and contract them within such narrow limits, that the whole may be seen as it were at once, and every thing material be collected from a few pages, concerning seventeen Provinces; a minute and circumstantial account of which would fill so many considerable volumes." (1765)

The author has displayed unusual talent in writing the text in the style of the period, and in hiding his identity behind that of Thomas

Pownall Keystone—a geographer created by Professor Brown. Following the preface and introduction, Professor Brown introduces in the prologue the character of geographer Keystone, his library, and his contemplated work, "Mirror for Americans."

"Mirror for Americans", proper, contains 14 chapters entitled, Natural Traits, A View of the Population, Ways of Travel, The Principal Occupations, The Maritime Interests, Seaboard Commerce, Northern Border Regions, Southern Border Regions, The Inlands of New York, Southern New England, Eastern Pennsylvania, The Chesapeake Country, The Carolina Low Country, and Selections from the Library of T. P. Keystone. In the words of Keystone, the text is "Embellished with illustrations and maps." In addition, Professor Brown has supplied an index and 39 pages of notes containing references to source material. All in all, Professor Brown is to be highly complimented for this excellent volume. (J. K. A.)

## AGRONOMIC AFFAIRS

### MEETINGS TO BE HELD AS SCHEDULED

AFTER careful consideration, the Executive Committee has definitely decided to hold the annual meeting of the American Society of Agronomy and Soil Science Society of America in Cincinnati November 10 to 12, inclusive, as originally scheduled. The Netherland-Plaza Hotel has been selected as headquarters. It is the feeling of your Executive Committee that these meetings are definitely linked with the war effort and that, in spite of transportation difficulties, we can best serve our nation by continuing with our original plans. A strong program has been built up to help point out ways in which agronomists may help in the war effort.

The general program of the Society will be addressed by Dr. L. A. Maynard of the School of Nutrition, Cornell University, who will talk on "The Soil and Crop Bases of Better Nutrition," and by Dr. O. E. May, Agricultural Research Administration of the U. S. Dept. of Agriculture, who will speak on "The Contribution of the Processing Laboratories to the War Effort Program."

The Soil Science Society general program will be a symposium on "The Efficient Use of Fertilizers During the War in Relation to the Major Soil Groups." In addition, the Soil Science Society will hold an evening meeting commemorating the 100th anniversary of the founding of the Rothamsted Experimental Station. Sectional programs will also deal with various problems relating to the war effort.

The Crops Section will have two general programs, one on "Agronomic Contributions and Their Current Significance", and the second on "Physiological Aspects of Agronomic Research." Sectional programs with special emphasis on war production include sessions on hemp, sugar beets, pastures, and crop breeding.

It is expected that the attendance may be smaller than in recent years but it is hoped that each state may be well represented and that these men will carry the message back to the other agronomists in their states.—G. G. POHLMAN, *Secretary*.

## DOCTOR BALL RETIRES

DOCTOR Carleton R. Ball, Principal Agriculturist and Executive Secretary of the Correlating Committee of the U. S. Dept. of Agriculture, the Tennessee Valley Authority, and the Valley-States Land-Grant Colleges since 1935, retired from the federal service on June 30, after 47 years in state (Iowa, California) and federal work. Entering the U. S. Dept. of Agriculture in 1899, he was Chief of the Division of Cereal Crops and Diseases from 1918 to 1930, in which period all its field work was brought into cooperation with the state experiment stations. During 1931–35, while with the Bureau of Public Administration, University of California, he authored two volumes covering the history and status of all government (federal, state, and county) cooperation in agricultural activities. Now, as a collaborator of the Department, he is located with the Extension Service, and is working on uncompleted projects, including a companion volume on cooperation in natural resources, a monograph of the willows, a history of American agriculture, and a little book on how to write technical manuscripts.

(N.B. Doctor Ball is a charter member of the Society and has served it in many capacities, including the presidency and the chairmanship of important committees. He was the first secretary and by virtue of that office edited the first four volumes of "Proceedings" to be published by the Society. He also inaugurated the publication of the present Journal in 1913 and served as editor of the JOURNAL through 1914. For this and other reasons, he is eminently qualified to write on the subject of the preparation of technical manuscripts.)

# JOURNAL
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## STAGE OF CUTTING STUDIES: I. GRASSES[1]


J. N. BIRD[2]


THE habit and rate of growth, season of maximum production, and duration of the period over which active growth occurs are all important factors in determining the adaptation of a species or strain of grass to management practice. Because they are different in these respects, species and strains react differently to cutting and grazing practices and this determines, to a large extent, the yield, feeding value, and longevity of their stands.

In Canada we have four grass species which are well adapted to the climatic and soil conditions prevailing throughout large areas of the more humid sections of the country. These are brome grass, *Bromus inermis* Leyss, timothy, *Phleum pratense* L., red top, *Agrostis alba* L., and Kentucky bluegrass, *Poa pratensis* L. They are the most productive and the most commonly used grass species in seed mixtures, and it is mainly for these reasons that they have been selected for comparison in this study.

Although stage of cutting studies have been carried out elsewhere with individual species of the group or of one species in comparison with one or two of the others, it was considered advisable to conduct a stage-of-cutting study which would include the entire group.

### STAGE OF CUTTING

The stage of growth which a plant has reached at the time of cutting is one of the most important considerations in connection with the harvesting of forage crops. Both the increased production of stem and resulting changes in the proportion of stem to leaf as a plant matures have a marked influence upon the yield and feeding value of the crop obtained. The rapid increase of stem during the period immediately preceding bloom and the withering and loss of


[1]Contribution from the Faculty of Agriculture of McGill University, Macdonald College, P. Q., Canada. Journal Series No. 160. Received for publication April 20, 1943.



[2]Lecturer in Agronomy. The author is indebted to Professor R. Summerby, Head of the Department of Agronomy, for assistance and advice in connection with this study, and to Mr. W. A. Brechin of the Chemistry Department for nitrogen and carotene determinations on samples.

lower leaves in the advanced stages of maturity account for marked changes not only in yield but also in the chemical composition, palatability, and digestibility of a grass plant in the later stages of growth.

Leaf tissue is known to be richer in protein, calcium, and carotene and lower in fibre than stem tissue. The significance of leaf and stem in determining the chemical composition and feeding value of grasses has been pointed out by Fagan and Jones (3)[3] and, more recently, by Hosterman and Hall (6). Many studies on the chemical composition and feeding value of grasses have been reviewed by Arny (1), Graves, *et al.* (4), and Huffman (7).

In general, all such studies have shown that as a grass plant approaches maturity, the percentage of protein decreases while the percentage of crude fibre increases; that, with the slackening off in growth during the advanced stages of maturity, there is a pronounced decline in the palatability and digestibility of the herbage; and that an increase in yield of dry matter in the advanced stages of maturity is obtained only at a sacrifice of feeding value.

Where perennial hay and pasture grasses are concerned, no study can be regarded as complete which does not take into account the yield of later cuttings, especially those produced in the same year. The stage of growth at which the first cutting is made determines the period over which aftermath growth may take place and, together with seasonal and soil conditions, the extent of this growth. Furthermore, the cutting treatment used in any year may influence the yield obtained in the following year.

## MATERIALS AND METHOD

According to the original plan, seedings of the four species of grasses were to be made each year in late July, without a nurse crop, and yields were to be taken in the second year following seeding. This was to allow for a thorough establishment of stands of all species. After following this plan for a 3-year period, it was revised in favor of yields taken in the first year after seeding, as it seemed possible to get well-established stands of all species by this time. The revised plan was followed for the three remaining years of the study.

Although it was originally planned to obtain yields in only one year from each test, opportunity was taken on two occasions to measure a possible after-effect of the cutting treatments used. This was done by taking a hay cutting at the late-bloom stage from all plots of each species which had been subjected to selected cutting treatments in the previous year (Table 3).

In selecting the stages of growth at which the cutting treatments would be made, the necessity of having easily identified stages was kept in mind. In the first three of the six tests involved in this study (series I), the cuttings were made at what might be called "hay" stages, *viz.*, beginning of heading, beginning of bloom, end of bloom, and when seed had formed. As no aftermath cuts were taken from this series, the yields reported are for the first (hay) cutting only. In the last three tests (series II) two earlier "grass" stages were introduced. The first of these, short grass, permitted five to six cuttings to be made per season while the second, long grass, permitted two to four cuttings, depending

[3]Figures in parenthesis refer to "Literature Cited", p. 860.

on the species and the seasonal growth conditions. In series II both a hay and an aftermath cutting were taken from the remaining four "hay" stages already mentioned.

The cuttings at the short grass stage were made on the same date for all species. They were made with a rotary-bar mower set fairly close to the ground in order to simulate, as far as possible, a close-grazing treatment. The cuttings at all other stages were made on dates which varied considerably with each species and for these a sickle-bar mower was used. The nature of the growth of the four species at the different cuttings from the six stages is illustrated in Figs. 1 to 4.

The plot arrangement followed essentially the same plan throughout the study. There were four, large species plots randomized within each of four blocks in a 2×2 arrangement so that the blocks were almost square. Within each of these large species plots, sub-plots for the various stages of cutting treatments were randomized.

Yields were calculated in tons of dry matter per acre and the data statistically analysed by the variance method. Only the summaries are presented in this paper. The principal details relative to the experimental procedure are summarized in Table 1.

TABLE 1.—*Details relative to experimental procedure.*

| Series No. | Seeding year | Harvest year | Number of species | Number of replicates | Size of plot* | Number of stages |
|---|---|---|---|---|---|---|
| I | 1933 | 1935 | 3 | 4 | 7×40 links | 4 |
| I | 1934 | 1936 | 4 | 4 | 7×40 links | 4 |
| I | 1935 | 1937 | 4 | 4 | 7×40 links | 4 |
| II | 1936 | 1937 | 4 | 2 | 6×40 links | 6 |
| II | 1938 | 1939 | 4 | 4 | 6×40 links | 6 |
| II | 1939 | 1940 | 4 | 4 | 5×40 links | 6 |

*Net size of plot harvested after removal of borders.

## RESULTS

### SEASONAL DEVELOPMENT

The four species of grasses used in this study varied considerably in the time of year at which they reached corresponding stages of growth. The average dates at which they reached the various stages are shown in Table 2. The actual dates, of course, varied somewhat from year to year with different seasonal conditions. At certain stages the grasses proved more sensitive to seasonal conditions

TABLE 2.—*Average date at first cutting, series I and II.*

| Stage of cutting | Brome grass | Timothy | Red top | Kentucky bluegrass |
|---|---|---|---|---|
| 1, short grass | May 21 | May 21 | May 21 | May 21 |
| 2, long grass | May 29 | May 29 | June 13 | May 29 |
| 3, begin to head | June 5 | June 14 | June 23 | May 29 |
| 4, begin to bloom | June 23 | June 28 | July 4 | June 11 |
| 5, end of bloom | June 29 | July 6 | July 12 | June 19 |
| 6, seed formed | July 6 | July 19 | July 19 | June 25 |

than at others. For example, at stage 4, the beginning of bloom was delayed by cool showery weather and hastened by dry sunny weather. Brome grass proved especially sensitive at this stage and its irregular behavior made the identification of its beginning-of-bloom stage rather difficult. The development of Kentucky blue-

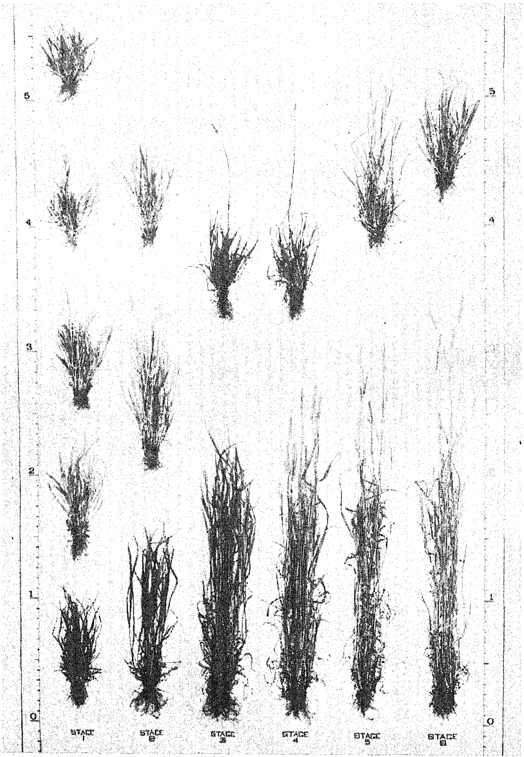


FIG. 1.—Samples of timothy from cuttings made at different stages of growth.

grass during late May and early June was so rapid that it was impossible to make any clear distinction between stages 2 and 3 with this species, hence the data for the two stages are essentially the same.

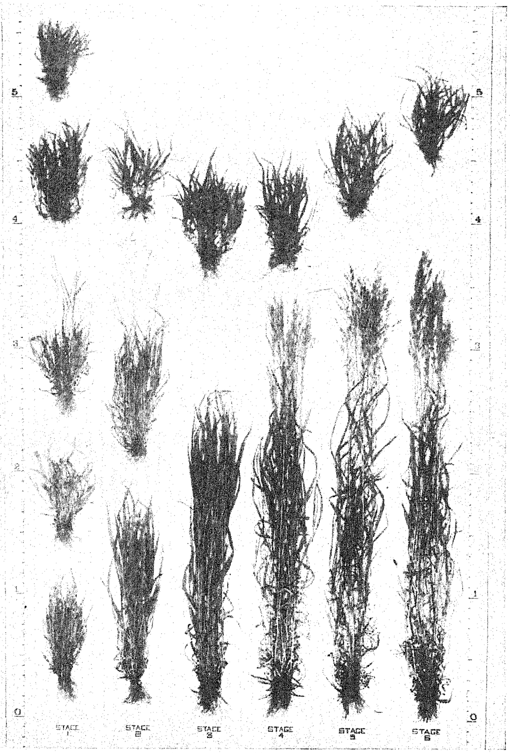


FIG. 2.—Samples of brome grass from cuttings made at different stages of growth.

YIELDS AT FIRST CUTTING, "HAY" STAGES

Yields obtained at the first cutting of the four "hay" stages are presented in the first section of Table 3. The analysis of variance for the data in Table 3 is given in Table 4. Data for the years 1935, 1936, and 1937 from series I and for the years 1939 and 1940 from

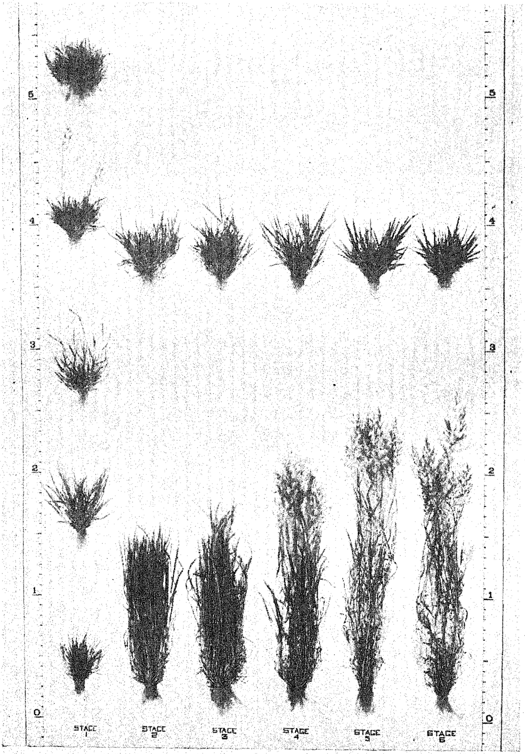


FIG. 3.—Samples of red top from cuttings made at different stages of growth.

series II have been combined to provide a 5-year average. Data for the year 1937 from series II have not been used in this comparison as they were based upon two replications only, whereas all other data were based upon four replications. It should also be pointed out that the yields obtained in series I were somewhat

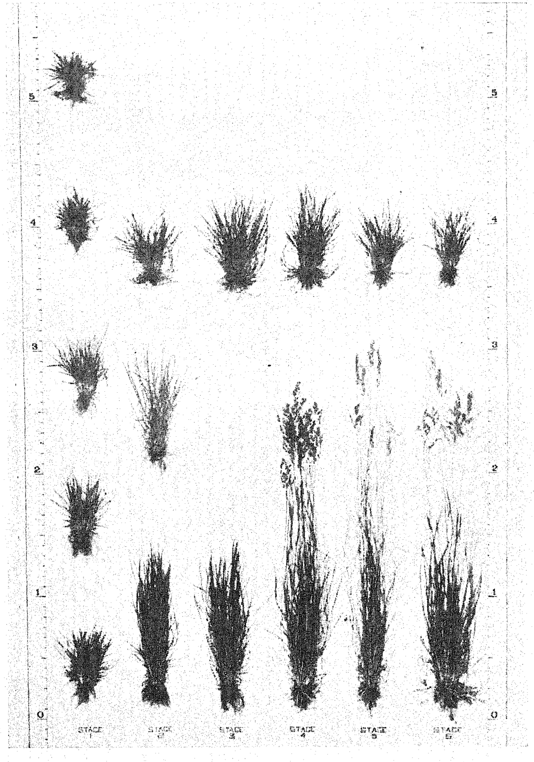


FIG. 4.—Samples of Kentucky bluegrass from cuttings made at different stages of growth.

TABLE 3.—*Yields of grasses cut at different stages of growth.*

| Stage of cutting | Yields at first cutting, "hay" stages, 5-year mean, dry yield in tons per acre, series I and II combined, 1935, 1936, 1937, 1939, 1940 | | | | | Yields from all cuttings, all stages, 3-year mean, dry yield in tons per acre, series II, 1937, 1939, 1940 | | | | | After effect of cutting treatments, 2-year mean, dry yield of hay in tons per acre, series II, 1940 and 1941 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Brome grass | Timothy | Red top | Kentucky bluegrass* | Means for stages (3 species) | Brome grass | Timothy | Red top | Kentucky bluegrass | Means for stages (4 species) | Brome grass | Timothy | Red top | Kentucky bluegrass | Means for stages (4 species) |
| 1, short grass | — | — | — | — | — | 1.34 | 1.37 | 1.24 | 1.18 | 1.28 | 1.06 | 1.04 | 0.97 | 0.85 | 0.98 |
| 2, long grass | — | — | — | — | — | 1.79 | 1.87 | 2.19 | 1.47 | 1.83 | 1.03 | 1.04 | 1.09 | 0.79 | 0.99 |
| 3, begin to head | 1.28 | 1.35 | 1.35 | 0.65 | 1.33 | 2.46 | 2.64 | 2.38 | 1.79 | 2.32 | 1.32 | 1.21 | 1.13 | 0.83 | 1.12 |
| 4, begin to bloom | 2.14 | 1.74 | 1.54 | 1.03 | 1.81 | 3.31 | 2.88 | 2.72 | 2.00 | 2.73 | 1.57 | 1.28 | 1.19 | 0.87 | 1.23 |
| 5, end of bloom | 2.25 | 1.79 | 1.65 | 1.17 | 1.90 | 3.22 | 2.95 | 2.55 | 2.26 | 2.75 | 1.28 | 1.34 | 1.04 | 0.92 | 1.15 |
| 6, seed formed | 2.37 | 1.95 | 1.54 | 1.28 | 1.95 | 3.39 | 2.89 | 2.48 | 2.30 | 2.76 | 1.33 | 1.36 | 1.01 | 0.94 | 1.16 |
| Means for species | 2.01 | 1.71 | 1.52 | 1.03 | — | 2.58 | 2.43 | 2.26 | 1.83 | — | 1.26 | 1.21 | 1.07 | 0.87 | — |
| Difference for significance (P=0.05) in comparison of: | | | | | | | | | | | | | | | |
| Means for species | 0.14 | | | | | 0.18 | | | | | 0.19 | | | | |
| Means for stages | 0.05 | | | | | 0.03 | | | | | 0.08 | | | | |

*Not included in analysis of variance; yields for 4 years only.

lower than those of series II with which they were combined. This would be expected in view of the fact that the yields from series I were obtained in the second year after seeding and therefore under conditions less favorable to pure grass stands than those of series II.

TABLE 4.—*Analysis of variance for species, stages, and years as given in Table 3.*

| Variation due to | Yields at first cutting, "hay" stages | | Yields from all cuttings, all stages | | After effect of cutting treatments | |
|---|---|---|---|---|---|---|
| | Degrees of freedom | Variance | Degrees of freedom | Variance | Degrees of freedom | Variance |
| Years | 4 | 6.995** | 2 | 3.624** | 1 | 0.025 |
| Blocks | 15 | 1.561** | 7 | 0.662* | 6 | 0.733* |
| Species | 2 | 4.842** | 3 | 6.312** | 3 | 1.520** |
| Species × years | 8 | 0.756** | 6 | 0.816* | 3 | 0.787* |
| Error "A" | 30 | 0.163 | 21 | 0.236 | 18 | 0.196 |
| Stages | 3 | 4.915** | 5 | 14.822** | 5 | 0.313** |
| Stages × years | 12 | 0.119** | 10 | 0.582** | 5 | 0.039 |
| Stages × species | 6 | 0.784** | 15 | 0.617** | 15 | 0.079** |
| Stages × species × years | 24 | 0.168** | 30 | 0.266** | 15 | 0.027 |
| Error "B" | 135 | 0.023 | 140 | 0.006 | 120 | 0.024 |

*Significant at P = 0.05.
**Significant at P = 0.01.

A comparison of the means for stages shows a significant increase for each successive stage later than the beginning of heading when the yields of brome grass, timothy, and red top are combined. Although Kentucky bluegrass has not been included in the analysis of variance it shows a similar trend. When the three species referred to above are considered individually there are only two cases where the yield is not significantly superior to that of the preceding stage, *viz.*, timothy at stage 5 and red top at stage 6.

A comparison of the means for species shows superiority for brome grass, the highest yielding species of the group. Timothy is significantly superior to red top, while Kentucky bluegrass is the lowest yielding species. If the first three species are compared within the same stage, it is found that there are no significant differences at stage 3, beginning of heading, but brome grass is significantly superior to all other species at all the remaining stages. Timothy is significantly superior to red top only at stage 6.

## YIELDS FROM ALL CUTTINGS, ALL STAGES

Yields obtained from two or more cuttings made at each of six stages of growth for the four grass species in series II are tabulated in the second section of Table 3. A comparison of the means for stages shows a significant increase for each successive stage as far as stage 4, beginning of bloom, when the yields of the four species are combined. Beyond this stage the increases are not significant.

When the four species are considered individually, there is also an increase in yield with each successive stage as far as stage 4, but thereafter no consistent trend is shown. Red top actually shows a significant decline in yield beyond this stage.

A comparison of the means for species shows that, although brome grass under these conditions is still a high-yielding species, its superiority over timothy does not reach the 5% level of significance. The yields of timothy and red top are not significantly different from one another, while Kentucky bluegrass is, again, the lowest yielding species of the group. When the four species are compared within the same stage, it is of interest to note that, under the conditions of this experiment at least, there is no significant difference in the yielding ability of the four species at stage 1, short grass. Kentucky bluegrass is a significantly lower yielding species than the others at stages 2, 3, and 4, beyond which the yields of red top decline to such an extent as to render the differences between this species and Kentucky bluegrass of no significance. The other two species, brome grass and timothy, continue significantly superior to Kentucky bluegrass at the later stages. Brome grass is significantly superior to red top from stage 4 onwards and significantly superior to timothy at stage 6. While there is no significant difference in yield between timothy and red top at any stage under the conditions of this experiment, it is perhaps worthy of note that the yields of timothy are higher at five of the six stages.

## AFTER EFFECT OF CUTTING TREATMENTS

It might be expected that such diverse cutting treatments, as those employed in this study would have some influence upon the yields of hay obtained in the following year from the same plots. In order to measure such an after effect, all the plots of each species in series II were cut simultaneously in the late bloom stage for each species in 1940 and 1941. The yield data obtained measure the after effect of the six regular cutting treatments in 1939 and 1940, respectively, and are shown in the last section of Table 3.

When the mean yields of the four combined species following the six different cutting treatments are compared, it is noted that significant depressions in yield follow the treatments made at the "grass" stages, 1 and 2, as compared with those made at the later "hay" stages. The after effect, however, varies greatly with the different species as one might expect, having in mind their differences in habit of growth. The low-growing species, red top and Kentucky bluegrass, are scarcely influenced by the varied cutting treatments, whereas the taller growing species, timothy and brome grass, show much less tolerance of the frequent cutting treatments given at stages 1 and 2. Cuttings made at stage 4, beginning of bloom, appear to have had a more favourable after effect upon the yields of brome grass and red top than other cutting treatments employed in this study.

A comparison of the means for species again reveals Kentucky bluegrass as a low yielder, but mean yields of the other three species are not significantly different.

## CRUDE PROTEIN

Nitrogen determinations were made in the Chemistry Department of Macdonald College on samples from all cuttings of all treatments employed in series I in 1936 and from those of series II in 1937. Essentially similar results were obtained in the two years. The calculated percentages of crude protein ($N \times 6.25$) of these samples on a dry basis for the year 1937 are shown in Table 5.

All species show a marked decline in percentage of crude protein during the first three stages, which is to be expected as a result of a period of rapid stem elongation. When the four species are compared with respect to their crude protein content, it is noted that the differences between them are small in comparison with differences between stages of cutting within species.

An important seasonal influence upon percentage of crude protein is shown in the first section of Table 6, where a comparison is made of the crude protein content on a dry basis of six clippings from the four species of grasses at stage 1, short grass, during the season of 1937. All species show a midsummer depression in percentage of protein.

The yields of crude protein per acre for all cuttings of the four species in 1937 have been calculated and are presented in Table 7. In this year, brome grass gave the highest yield of crude protein per acre, red top and timothy were intermediate, and Kentucky bluegrass was the lowest of the group. Timothy appeared to reach its peak of protein yield at an earlier stage than the other three species. The highest mean yield of crude protein from the four species was obtained from the cutting treatment at stage 4, beginning to bloom.

## CAROTENE

Carotene determinations were also made in the Chemistry Department on a complete set of the cuttings taken at all six stages from the four species, series II, in 1939. These determinations were made by the method of Guilbert (5), using 2-gram samples of the fresh herbage and employing an Evelyn photoelectric colorimeter with 440 $\mu$m filter for measuring the color of the final carotene solutions.

The carotene content in milligrams per 100 grams of dry matter for all clippings made at stage 1, short grass, is presented in Table 6. On the basis of the mean carotene content for the five clippings made during the season, it will be observed that brome grass ranks highest among the four species. Kentucky bluegrass, however, is the leading species at the last clipping date, September 29. It may also be noted that the general seasonal trend in carotene content of clippings made at this short-grass stage in 1939 bears a fairly close relationship to the seasonal trend in crude protein content shown for the season of 1937 in the same table.

The carotene content on a moisture-free basis for the first cuttings made at six different stages of growth in 1939 is presented in Table 5. Here again it will be noted that the trend in carotene with the various stages in 1939 shows a fairly close relationship to the trend in crude protein for these same stages in 1937.

TABLE 5.—*Crude protein and carotene content, on dry basis, of four grasses at six stages of cutting, Series II.*

| Stage of cutting | Percentage of crude protein, 1937 | | | | | Carotene, MG/100 grams, 1939 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Brome grass | Timothy | Red top | Kentucky bluegrass | Means of 4 species | Brome grass | Timothy | Red top | Kentucky bluegrass | Means of 4 species |
| 1, short grass....... | 16.60 | 16.08 | 16.90 | 15.30 | 16.22 | 52.5 | 47.4 | 49.8 | 46.4 | 49.0 |
| 2, long grass........ | 14.96 | 13.99 | 11.59 | 13.42 | 13.49 | 36.0 | 33.6 | 37.7 | 32.2 | 34.9 |
| 3, begin to head..... | 11.22 | 8.15 | 8.17 | 11.61 | 9.79 | 18.9 | 19.4 | 19.2 | 32.2 | 22.4 |
| 4, begin to bloom.... | 7.40 | 6.19 | 7.14 | 8.49 | 7.30 | 18.9 | 10.4 | 20.7 | 26.2 | 19.0 |
| 5, end of bloom..... | 6.00 | 5.25 | 6.23 | 7.35 | 6.21 | 16.2 | 10.9 | 12.9 | 19.0 | 14.7 |
| 6, seed formed...... | 6.12 | 4.38 | 6.36 | 7.44 | 6.07 | 15.6 | 7.5 | 13.2 | 16.5 | 13.2 |
| Means............. | 10.38 | 9.01 | 9.40 | 10.60 | 9.85 | 26.3 | 21.5 | 25.6 | 28.7 | 25.5 |

TABLE 6.—*Crude protein and carotene content, on dry basis, of four grasses clipped at stage 1, short grass, Series II.*

| Percentage of crude protein at six intervals, 1937 | | | | | | Carotene, MG/100 grams, at five intervals, 1939 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cutting date | Brome grass | Timothy | Red top | Kentucky bluegrass | Means of 4 species | Cutting date | Brome grass | Timothy | Red top | Kentucky bluegrass | Means of 4 species |
| May 21.... | 16.6 | 16.1 | 16.9 | 15.3 | 16.2 | May 20... | 52.5 | 47.4 | 49.8 | 46.4 | 49.0 |
| June 1..... | 21.1 | 17.7 | 21.8 | 18.6 | 19.8 | June 1.... | 41.8 | 38.1 | 26.8 | 19.3 | 31.5 |
| June 24.... | 16.8 | 14.1 | 14.8 | 13.5 | 14.8 | June 19... | 41.2 | 29.7 | 43.7 | 39.0 | 38.4 |
| July 27.... | 15.6 | 12.6 | 14.6 | 13.9 | 14.2 | July 25.... | 29.7 | 13.5 | 29.8 | 25.9 | 24.7 |
| Aug. 23.... | 20.1 | 14.8 | 15.6 | 15.9 | 16.6 | Sept. 29... | 36.2 | 24.2 | 33.7 | 43.4 | 34.4 |
| Sept. 9..... | 18.5 | 14.9 | 14.6 | 15.7 | 15.9 | | | | | | |
| Means.... | 18.1 | 15.0 | 16.4 | 15.5 | 16.3 | Means.... | 40.3 | 30.6 | 36.8 | 34.8 | 35.6 |

In contrast with differences within species at the various stages of cutting used in this study, differences between species in carotene content may be considered quite small, especially in the earlier stages. In the more mature stages the carotene content of Kentucky bluegrass is maintained at a rather high level as compared with the other species, especially timothy.

Yields of carotene in pounds per acre for all cuttings at all stages of the four species in 1939 have been calculated and are presented in Table 7. On the basis of the yields obtained in this particular year, brome grass and red top have given relatively higher yields of carotene than the other two species. The highest mean yield of carotene per acre from the four species has been obtained from cutting treatments at the two "grass" stages. The decline in carotene yield from cutting treatments made at successively later stages has been particularly marked in timothy.

## DISCUSSION

When the yielding ability of all four species is considered, brome grass shows superiority when cut at the advanced stages of maturity but not at the immature stages. Possibly better results would have been obtained with this species if the cuttings at stages 1 and 2 had not been made so close to the ground level. Brome grass is not generally regarded as a species which is tolerant of close-clipping or grazing and this may account for its less favorable performance at the immature stages. On the other hand, the drought resistance of this grass enables it to continue growth at levels of soil moisture which greatly restrict the growth of the other three species involved in this study. Its earlier maturity, moreover, enables it to pass through its later "hay" stages under more favorable soil moisture conditions than usually obtain for the later maturing species, timothy and red top.

Kentucky bluegrass has proved inferior in yielding ability to the other three species under these conditions.

On account of wide variations in soil, seasonal, and regional conditions, the relative yielding ability of the four species may be expected to vary greatly from year to year and from place to place. The yield data presented above may therefore have a rather limited and local significance.

Since the study has been made with pure species alone, special care has been taken to maintain the plots free from volunteer species, including weeds. Furthermore, no attempt has been made to determine the influence of any associated legume upon the relative yielding ability or protein content of the different species.

There is a marked upward trend in the yield of all four grasses at first cutting for all stages up to stage 4, the beginning of bloom. Beyond this stage, however, such increases as are shown are of a small order. Even the inclusion of later cuttings to obtain the total seasonal yield for each stage does not change the general trend, although it diminishes the differences in yields from the various cutting treatments to some extent.

TABLE 7.—*Yield of crude protein and carotene from all cuttings of four grasses at six stages, Series II.*

| Stage of cutting | Crude protein, 1937, pounds per acre | | | | | Carotene, 1939, pounds per acre | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Brome grass | Timothy | Red top | Kentucky bluegrass | Means of 4 species | Brome grass | Timothy | Red top | Kentucky bluegrass | Means of 4 species |
| 1, short grass | 408 | 338 | 386 | 284 | 354 | 0.893 | 0.870 | 0.970 | 0.834 | 0.892 |
| 2, long grass | 484 | 400 | 406 | 334 | 406 | 0.973 | 0.781 | 1.226 | 0.684 | 0.916 |
| 3, begin to head | 480 | 408 | 392 | 292 | 394 | 0.826 | 0.758 | 0.798 | 0.662 | 0.761 |
| 4, begin to bloom | 598 | 374 | 434 | 360 | 442 | 0.974 | 0.534 | 1.030 | 0.804 | 0.835 |
| 5, end of bloom | 486 | 342 | 438 | 336 | 400 | 0.910 | 0.612 | 0.741 | 0.775 | 0.759 |
| 6, seed formed | 506 | 302 | 398 | 346 | 388 | 0.965 | 0.449 | 0.708 | 0.707 | 0.707 |
| Means for species | 494 | 362 | 410 | 326 | 398 | 0.923 | 0.667 | 0.912 | 0.744 | 0.812 |

Coincident with the marked upward trend in yield with the first four stages of cutting is a marked downward trend in percentage of crude protein in all four species. The peak in crude protein yield per acre appears to be reached at an earlier stage with timothy than with the other three species. This early peak in protein yield of timothy has already been noted by Evans, *et al.* (2)

A comparison of the variances, presented in Table 4, reveals highly significant interactions for stages × years, stages × species, and stages × species × years. There are also significant interactions for species × years. This would infer that yields obtained at the different stages used in this study differ greatly in different years and with different species. Furthermore, stages × species interactions are not similar from year to year, neither is the relative performance of different species the same from year to year. The importance of such interactive effects in a study of this kind is therefore indicated. Stage-of-cutting results obtained with one grass species cannot be applied unreservedly to another and results obtained at any single stage or with any single species in one year cannot be applied without reservations to other years.

In spite of the interactions noted above, comparative F values, summarized in Table 8, indicate highly significant differences for stages over and above the interactions in which they are involved. Significant differences are also shown for species over and above the interaction for species × years.

TABLE 8.—*Summary of F values for variances presented in Table 4.*

| For comparison of | First cutting | All cuttings | After effect |
|---|---|---|---|
| Species with species × years | 6.40* | 7.73* | 1.93 |
| Stages with stages × years | 41.3** | 25.5** | 80.8** |
| Stages with stages × species | 6.27* | 24.0** | 39.2** |
| Stages with stages × species × years | 29.2** | 55.8** | 11.7** |
| Stages × years with stages × species × years | 0.71 | 2.19* | 1.45 |
| Stages × species with stages × species × years | 4.67** | 2.32* | 2.97* |

*Significant at P = 0.05. **Significant at P = 0.01.

If the mean 5-year yields for brome grass, timothy, and red top as presented in Table 3 are corrected for the mean influence of both stages and species, the interactive effect of individual stages × species may be shown by the mean deviations for each stage and species from the mean yield of all three species at all four stages, as in Table 9. Compared with the other two species, brome grass is significantly lower yielding at stage 3 while red top is significantly higher yielding at this stage. However, at stage 6 the situation is completely reversed, with brome grass the higher yielding and red top the lower yielding species. Timothy occupies an intermediate position, being superior to brome grass and inferior to red top at stage 3 and inferior to brome grass but superior to red top at stage 6, as judged by the 5% level of significance.

TABLE 9.—*Mean deviations after correction for mean influence of stages and species in Table 3, yields at first cutting, "hay" stages, 5-year mean, 1935, 1936, 1937, 1939, 1940.**

| Stage of cutting | Brome grass | Timothy | Red top |
|---|---|---|---|
| 3, begin to head | −0.305 | +0.060 | +0.246 |
| 4, begin to bloom | +0.065 | −0.026 | −0.039 |
| 5, end of bloom | +0.090 | −0.070 | −0.019 |
| 6, seed formed | +0.149 | +0.036 | −0.186 |

*Difference for significance ($P = 0.05$) in comparison of deviations 0.088.

## SUMMARY

Brome grass, timothy, red top, and Kentucky bluegrass were compared at six different stages of growth, *viz.*, short grass, long grass, beginning of heading, beginning of bloom, end of bloom, and when seed had formed.

When the yields of all cuttings were added together so as to obtain a total seasonal yield for each stage, the combined yields of the four species showed a significant increase with each successive stage as far as the beginning of bloom, after which the increases in yield were not significant.

When the yields at first cutting for the four "hay" stages were compared, the combined yields of brome grass, timothy, and red top showed a significant increase with each successive stage later than the beginning of heading.

Brome grass was the highest yielding species of the group, under these conditions, Kentucky bluegrass was the lowest, while timothy and red top occupied an intermediate position.

The percentage of crude protein decreased with each successive stage of cutting. The decline was more rapid, however, during the earlier stages coincident with a period of rapid stem elongation. The peak of crude protein yield for the four species combined was reached at the beginning of bloom. Brome grass gave the highest yields of crude protein per acre. Timothy appeared to reach the peak of its protein yield at an earlier stage than the other three species under these conditions.

The carotene content also declined with successively later stages of cutting. Differences between species were small when compared with differences within species, especially in the earlier stages. At the more mature stages Kentucky bluegrass maintained a relatively higher and timothy a relatively lower level of carotene content than the other two species.

Highly significant interactions were obtained for stages × years, stages × species, and stages × species × years.

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# "NATURAL CROSSING" OF WHITE CLOVER BY BEES[1]

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ALTHOUGH an understanding of the mode of pollination is generally considered a prerequisite to the intelligent planning and pursuing of a profitable breeding program, detailed information on this subject has not been available previously for white clover (*Trifolium repens* L.). It has long been recognized, however, that honey bees are the most common pollinating insects for white clover and that seed set in the open is usually good if pollination has been adequately effected under proper environmental conditions. Since it was also known that most clones of white clover are self-sterile (9, 7, 2),[3] it has generally been assumed that the species should be classed as naturally cross-pollinated under most circumstances. Though this assumption may hold for the majority of clones, the present study shows that it certainly does not apply to those bearing the self-compatibility factor (4).

An important consideration in any study of this kind is the selection of typical clones to be tested, especially if different degrees of self-compatibility occur within the species. This is particularly true with white clover, where genetically distinct types have been demonstrated, ranging from almost complete self-incompatibility (1) through all intermediate grades of pseudo-self-compatibility (3) to very high degrees of true self-compatibility (4). Since all except the clones with the lowest seed-setting ability following self-pollination have been useful in establishing inbred lines, it seemed desirable to learn how the different degrees of self-compatibility might affect the ultimate combining of selected plants.

The best measure of natural crossing is obtained when clones differing in an easily recognized genetic character are allowed to cross in the open. By classifying the progeny obtained from the recessive parent, a direct measure of the amount of crossing is secured. This procedure demands adequate isolation to prevent crossing between any except the selected clones, but in the case of white clover isolation is difficult to find. Since many insects besides honey bees visit white clover and since the species is practically omnipresent near cultivated areas, isolation was obtained in the present study by the use of cages placed over the selected clones increased vegetatively in the field for this purpose.

## MATERIALS AND METHODS

The two clones selected as males[4] for the crosses in this study were homozygous, respectively, for two dominant genetic markings, purple leaf color and V-shaped

[1]Contribution No. 54, of the U. S. Regional Pasture Research Laboratory, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, State College, Pa., in cooperation with the northeastern states. Received for publication April 26, 1943.

[2]Associate Agronomist.

[3]Figures in parenthesis refer to "Literature Cited", p. 869.

[4]All normal flowers of white clover are perfect, but for convenience in reference the seed parent will be considered as the female and the pollen parent as the male.

white marking on the leaf blade. Both markings are inherited as simple Mendelian dominants, and both are easily classified in the seedling stage.

One of the nine clones selected as female showed a high degree of self-compatibility. This was the same clone as the male parent (9–II) used in a previous study of the genetics of self-compatibility (4). The other eight females ranged from high to low pseudo-self-compatibility and were selected because they were parents or potential parents of inbred lines. Inbreeding has been continued into the second generation from four of the parents, and as far as production of selfed seed was concerned all lines could have been continued. The plant with the highest degree of pseudo-self-compatibility (plant B, Table 1) was used previously as the female parent (2-1) in a genetic study of this character (3).

The method of using bees for crossing under cages was the same as outlined previously (2). The individual cuttings, however, were surrounded by 2×2 foot wooden frames extending about 3 inches above the surface of the soil in order to prevent intermingling of the stolons and flower heads from the two clones in each cage. In this way it was possible to include a total of eight cuttings within each 4×8 foot cage. Four of the cuttings under each cage were of the same male parent clone, and these were arranged in alternate positions with the four cuttings of one recessive female. The plants were caged in the flush of bloom during June and July of their second summer in the field, and ripe seed was harvested soon after removing the cage in late July or early August. For classification the seedlings were grown in flats in the greenhouse each year during October and November.

In analyzing for covariance, the procedure suggested by Snedecor (8) was followed.

## EXPERIMENTAL RESULTS

### SELF-COMPATIBILITY OF CLONES

Considerable variation has always been noted in measuring the degree of self-compatibility for any clone of white clover. The number of selfed seeds varies widely not only between different cuttings of the same clone, but also between different heads on a single cutting. The difference between years is often great, but significant interannual correlations are generally obtained, even with pseudo-self-compatible clones (3). The nine female clones used in this study have been self-pollinated under bags in the field for four or five years, but only the results for 1942 are presented (Table 1). The average for each clone is based on 23 to 50 heads harvested from three to five cuttings. Although the seed set for clone A (75.4) is considerably lower than that obtained in previous years (e.g., 159.3 in 1940), this clone exhibits much greater self-compatibility than the others. Since, in addition, clone A possesses the $S_f$ allele which none of the other clones have, it has not been included with the others when analyzing for inter-clone differences.

The other eight female clones varied from an average of 15.2 seeds per head to 0.2. When the variance between clones was compared with that within clones, a highly significant F value was obtained. Here, likewise, the averages were lower than in some previous years, but the order of the different clones was much the same, at least for those showing significant differences.

TABLE 1.—*Summary of seeds per head from selfing, seeds per head obtained under bee cages, percentage germination of the latter, and percentage crossing for nine plants of white clover enclosed under 23 cages during two years.*

| Clone No. | No. of seeds per head from selfing | Cage No. | Year caged | ♂ marking | No. of seeds per head (tested heads) | Germination, % | Total plants classified | Crossing, % |
|---|---|---|---|---|---|---|---|---|
| A | 75.4 | 1 | 1942 | P* | 147.1 | 60.4 | 2,418 | 18.8 |
| B | 15.2 | 2 | 1941 | V* | 101.7 | 65.7 | 887 | 85.0 |
| | | 3 | 1942 | V | 19.4 | 82.8 | 1,325 | 89.2 |
| | | 4 | 1942 | V | 54.3 | 62.8 | 856 | 91.7 |
| | | 5 | 1942 | P | 53.3 | 50.3 | 677 | 92.3 |
| C | 6.2 | 6 | 1941 | V | 103.0 | 46.4 | 788 | 100.0 |
| | | 7 | 1942 | V | 20.1 | 76.1 | 1,213 | 97.6 |
| | | 8 | 1942 | V | 53.6 | 58.1 | 819 | 99.0 |
| | | 9 | 1942 | P | 68.9 | 55.8 | 800 | 99.6 |
| D | 3.5 | 10 | 1941 | V | 73.2 | 67.1 | 1,006 | 99.4 |
| | | 11 | 1942 | V | 19.0 | 86.9 | 1,024 | 98.5 |
| | | 12 | 1942 | V | 18.4 | 82.9 | 982 | 98.8 |
| | | 13 | 1942 | P | 55.9 | 70.3 | 764 | 100.0 |
| E | 3.1 | 14 | 1941 | V | 53.8 | 58.4 | 1,139 | 98.3 |
| | | 15 | 1942 | P | 12.3 | 90.6 | 649 | 96.1 |
| F | 2.8 | 16 | 1941 | V | 74.5 | 66.5 | 1,330 | 98.5 |
| | | 17 | 1942 | P | 55.8 | 51.0 | 749 | 96.8 |
| G | 1.5 | 18 | 1941 | V | 71.9 | 55.8 | 1,089 | 98.9 |
| | | 19 | 1942 | P | 10.0 | 78.7 | 590 | 89.5 |
| H | 0.9 | 20 | 1941 | V | 115.7 | 72.8 | 1,455 | 99.8 |
| | | 21 | 1942 | P | 65.6 | 72.2 | 1,040 | 99.2 |
| I | 0.2 | 22 | 1941 | V | 57.2 | 58.4 | 1,139 | 99.8 |
| | | 23 | 1942 | P | 14.8 | 72.6 | 385 | 98.2 |

*P = purple leaf; V = V-shaped white area on leaf blade (see text).

The purple- and white-marked male clones averaged 5.0 and 19.1 seeds per head when selfed under bag at the same time as the females, but from previous crosses in the greenhouse (3) it was thought that such differences as this in pseudo-self-compatibility of the males would not influence their relative ability to effect cross-pollination when mated with unrelated females.

## AMOUNT OF CROSSING

In order to measure the percentage crossing of the different female clones, 23,124 seedlings were classified, the number for different cages varying from 385 to 2,418. The most striking feature of the results was the fact that percentage crossing for different cages varied from 18.8 to 100.0. Since clone A, which bore the $S_f$ allele, crossed only 18.8%, it could be classed as an "often cross-pollinated" plant. The question arises whether the percentage crossing should be doubled for clone A in order to account for sibbing which might have taken place within the cage. This procedure is regularly used with the self-fertile, naturally self-pollinating cereals, and in some respects clone A behaves in a similar manner. Its high degree of self-compatibility following bee pollination was noted in the 1940 seed set (2) when an average of 173.7 seeds per head was obtained

from this clone caged by itself. Although it is not as highly autogamous as some other clones of white clover, it has regularly set selfed seed without artificial pollination when isolated in both greenhouse and field. Furthermore, a total of 758 heads were produced on plant A, and at certain times during the flowering period they may have been slightly more numerous than those on the male parent. From this latter factor one might feel justified in assuming that the bees would carry pollen to a head on clone A just as frequently from another head on the same clone as from a head on the male parent. Consequently, to double the percentage crossing might give a better estimate for the crossing potentialities of a single isolated cutting.

In this sort of adjustment of percentage crossing, it is also necessary to assume that there would be equal chances for fertilization when pollen from two clones was mixed on the stigma. From a genetical study, however, of the $S_f$ allele (4 and unpublished data), it has been shown that pollen bearing $S_f$ does not compete equally well with pollen bearing other alleles when the two are applied together. It has also been shown that the second factor carried in a heterozygous self-compatible clone has an inhibiting influence on pollen bearing the same allele. In other words, both types of pollen produced by an $S_fS_x$ clone such as A should be at a disadvantage when growing on their own stigma in competition with pollen bearing unrelated alleles. The only way one could obtain 81.2% selfing and 18.8% crossing, therefore, would be to have a large excess of self pollen over cross pollen on the stigmas of clone A. Assuming that for most of the time there were approximately equal numbers of flowers on both clones under the cage, there are at least two explanations for the high amount of selfing. Either the bees tended to move more among the cuttings of A than at random between the two different clones, although this was not evident from watching the bees, or they failed to carry enough pollen from the purple male to cross adequately all flowers visited on a single trip to the A heads. It is quite possible, therefore, that under other conditions a much higher percentage crossing would be obtained, and that 18.8% should be considered closer to a minimum rather than a maximum estimate for this self-compatible clone.

Evidence that varying amounts of crossing could be secured under other conditions was obtained from an analysis of the variation within this cage. The 4,000 seeds used for the test were chosen by taking 100 at random from each of 10 good heads harvested on each of the four cuttings. Considerable variation was obtained not only between heads but also between cuttings (Table 2), and an analysis of variance showed the differences between cuttings to be highly significant. When these differences were adjusted by covariance to a common basis in regard to either seeds per head or percentage germination, the F value was lowered from 5.48 to 4.56 and 5.12, respectively, but the differences were still highly significant. An explanation of these differences between cuttings may perhaps be found in the behavior of the bees. The hive was located at the end of the cage near cutting 1, and the percentage crossing decreased

continuously from this end to the other (Table 2). It was noticed that the bees did not fly directly to a flower head on leaving the hive; instead most of them flew to the top of the cage for some time before dropping to the flowers. Since the prevailing winds often carried the bees to the end of the cage with cutting 4, it is reasonable that this cutting should be crossed the least, and that as the bees moved back toward the hive, they gathered more male pollen and consequently effected a higher percentage crossing. Similar gradients were observed in some other cages, but the differences were often small and in most of them there was no adequate test of significance.

TABLE 2.—*Variation in percentage crossing obtained from different heads of plant A.*

| Cutting No. | Percentage crossing | | |
|---|---|---|---|
| | Maximum | Minimum | Average |
| 1 | 44.8 | 8.3 | 25.5 |
| 2 | 39.4 | 7.8 | 25.0 |
| 3 | 39.6 | 8.0 | 19.5 |
| 4 | 14.5 | 5.4 | 9.8 |

The percentage crossing obtained with the eight pseudo-self-compatible clones was very much higher than that with clone A (Table 1), the different cages varying from 85.0 to 100.0%. There appeared to be a slight inverse relationship between the amount of pseudo-self-compatibility and the amount of crossing. The clone with the highest seed set crossed the least and the clone crossing the most was next to lowest in seed set, but the correlation coefficient was not significant ($r = -0.026$). In order to test significance of differences between clones in amount of crossing, the data were grouped in two ways. In the first place, since each clone was caged at least once in each year, these 16 comparable cages were considered together and the clone differences tested by clones × years interaction. Secondly, since three of the clones were replicated using three cages each during 1942, these nine cages were considered together and the differences tested by clones × replications interaction.

With the eight clones caged both years, neither the difference between clones nor between years was significant. When the clone differences were adjusted by covariance, however, to a common basis in regard to percentage germination (Table 3), the F value was raised from 2.71 to 5.06, a significant value. A similar adjustment for seeds per head lowered the F value to 2.36. The differences between clones in percentage germination were not significant, but those in seeds per head were highly significant.

With the second method of summarizing using only the three clones replicated in 1942, the differences between clones were highly significant and those between replications were significant. After adjusting the clone differences to a common percentage germination (Table 4) or number of seeds per head by covariance, the F value

TABLE 3.—*Analysis of covariance for percentage germination (x) and percentage crossing (y) among eight pseudo-self-compatible plants enclosed under bee cages during two years.*

| Source of variation | D. F. | Sums of squares and products | | | Correlation coefficient | Regression coefficient | Errors of estimate | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $Sx^2$ | $Sxy$ | $Sy^2$ | | | Sum of squares | D. F. | Mean square |
| Plants | 7 | 776.90 | 122.45 | 257.45 | 0.2730 | 0.1577 | — | — | — |
| Years | 1 | 108.68 | −22.67 | 4.73 | — | −0.2086 | — | — | — |
| Error | 7 | 830.57 | −191.98 | 95.01 | −0.6815 | −0.2311 | 50.64 | 6 | 8.44 |
| Total | 15 | 1716.16 | −92.20 | 357.19 | −0.1178 | −0.0537 | — | — | — |
| Within cages | 44 | 5478.00 | 685.05 | 645.07 | 0.3641* | 0.1251 | — | — | — |
| Plants+error | 14 | 1607.47 | −69.53 | 352.46 | — | — | 349.45 | 13 | — |
| Difference for testing adjusted plant means | | | | | | | 298.81 | 7 | 42.69† |

*Significant according to Fisher's (5) table V, A.
†F = 5.06, exceeding odds 20:1.

was raised from 285.45 to 429.23 and 446.50, respectively. The differences between clones were not significant for either percentage germination or seeds per head.

TABLE 4.—*Analysis of covariance for percentage germination (x) and percentage crossing (y) among three pseudo-self-compatible plants each enclosed under three replicated bee cages in 1942.*

| Source of variation | D. F. | Sums of squares and products | | | Correlation coefficient | Regression coefficient | Errors of estimate | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $Sx^2$ | $Sxy$ | $Sy^2$ | | | Sums of squares | D. F. | Mean square |
| Plants | 2 | 470.21 | 121.10 | 130.96 | 0.4880 | 0.2575 | — | — | — |
| Replication | 2 | 836.51 | −74.33 | 6.68 | −0.9940 | −0.0889 | — | — | — |
| Error | 4 | 159.49 | −9.18 | 0.92 | −0.7581 | −0.0576 | 0.39 | 3 | 0.13 |
| Total | 8 | 1466.21 | 37.59 | 138.56 | 0.0834 | 0.0256 | — | — | — |
| Within cages | 25 | 1925.75 | 108.93 | 70.20 | 0.2963 | 0.0566 | — | — | — |
| Plants+error | 6 | 629.70 | 111.92 | 131.88 | — | — | 111.99 | 5 | — |
| Difference for testing adjusted plant means | | | | | | | 111.60 | 2 | 55.80* |

*F = 429.33, exceeding odds 99:1.

It might appear from the change in F values that consideration of the second variable was very worthwhile. When the reduction in error due to correction by regression was calculated, however, no significant effect was found for any of the four analyses described for these eight pseudo-self-compatible clones. Likewise, little relationship was shown between the pairs of characters either by the correlation coefficients or the regression coefficients. Only in the

case of correlation between percentage germination and percentage crossing for within cages (Table 3) was the value of r statistically significant. In all but one case, on the other hand, considerable change in rank for the adjusted mean percentages of crossing was observed. The adjustment makes the measure of crossing more precise, and since little extra work is involved in recording either seeds per head or percentage germination, it might be concluded that retention of these independent variables in similar experiments would be worth the trouble.

For each of the analyses there was also calculated the variance within cages in order to provide an estimate of the sampling error (6). Especially in the case of the eight clones caged both years (Table 3), this variance was fairly large in comparison with that attributable to clones, and it suggests that with this type of study several measurements should be made for each clone in order that the most accurate estimate of clone differences be obtained.

In 1941 the number of flowers on each head was also recorded. Since the variance between cuttings within cages was highly significant, its relationship to seeds per head was tested. The latter had shown significant differences both between cages and between cuttings. When the number of seeds per head was adjusted to a common basis in regard to flowers per head by analysis of covariance, the F values were lowered from 2.49 to 2.25 for cages and from 67.43 to 57.95 for cuttings. The former was now less than the 5% point (2.45), but the latter remained highly significant. The correlation coefficients for cages, cuttings, and total, respectively, were 0.74, 0.72, and 0.43, all of them significant. The reduction due to regression was significant for both cages and cuttings. Apparently, the number of seeds per head is in part a function of the number of flowers, but the latter does not account for all of the variation in the former.

## DISCUSSION

In most species where percentage crossing has been investigated previously, all individuals within the species are of approximately the same degree of self-fertility and consequently show similar amounts of crossing. The situation is considerably different in white clover where different clones range from almost complete self-incompatibility to high degrees of self-compatibility. Although clones with different degrees of pseudo-self-compatibility show significantly different amounts of crossing, for most practical breeding purposes the amounts of crossing are of a similar high degree. It might be inferred that plants of this type could be combined adequately if allowed to intercross in isolation.

In regard to the self-compatible clone, however, a different breeding procedure seems necessary. Combining clones of this type would not give adequate amounts of crossing, and it would probably be necessary to eliminate the $S_f$ gene by outcrossing before attempting to cross self-fertile lines. When the self-fertile plant was crossed under a cage, it was considered necessary to increase the percentage crossing in order to obtain the most valid estimate for a single isolated

plant. Under regular breeding circumstances, on the other hand, crossing would probably be attempted in somewhat the same manner as that used here, and an adjustment for possible sibbing serves no practical purpose.

The use of cages for this type of study has obvious disadvantages in comparison with natural crossing in the open. It was apparent that the flowers under the cage were being visited more frequently than those outside, and in several respects the behavior of the bees under the cage was not normal. On the other hand, the use of cages has the advantage of testing a larger number of clones under better controlled conditions. In addition, since it is possible to arrange clones under the cage in much the same manner as that which would be used for practical crossing, the results should have direct application.

The analysis of covariance proved a useful method of summarizing for these data. Significant differences in the adjusted means were demonstrable using covariance when the unadjusted means were not significantly different. Likewise, the ranking of the adjusted means was changed in several cases from the original order. The recommendation has been made (8) not to use covariance unless "there is a well-considered reason for doing so". The present study may be a borderline case, but since a certain gain in precision was noted, the little extra work in noting the independent variable would seem to be justified.

## SUMMARY

When eight clones of white clover which differed significantly in degree of pseudo-self-compatibility and which were recessive for two marker characters were crossed under bee cages during two years with other clones homozygous for these markers, the percentage crossing ranged from 85.0 to 100.0 for different cages and was significantly different for the eight clones. A slight inverse relationship may exist between the degree of pseudo-self-compatibility and the amount of crossing. Increased precision was gained when the percentage crossing was adjusted by analysis of covariance according to number of seeds per head or percentage germination.

In the case of a self-compatible clone, the percentage crossing was only 18.8, but several lines of evidence suggested that this should be a minmum rather than a maximum estimate for the clone. Since such widely different amounts of crossing may be expected within the species, it is evident that all clones should be investigated thoroughly at least for their self-compatibility before including them in a breeding program.

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# GROWTH OF STRAWBERRY CLOVER VARIETIES AND OF ALFALFA AND LADINO CLOVER AS AFFECTED BY SALT[1]

H. G. Gauch and O. C. Magistad[2]

IN RECENT years considerable interest has been shown in strawberry clover, *trifolium fragiferum*, because of its ability to grow under conditions of moderate salinity, and because of its applicability in the reclamation of water-logged, saline soils now considered as waste lands in the western United States (9, 13).[3] This legume, one of the more recent clover immigrants, is a perennial and native of eastern Mediterranean countries and of southern Asia Minor. It is believed to possess several advantages over alfalfa in that apparently it will tolerate more salinity (1, 11), will withstand flooding-over for as much as two months at a time (9), is shallow-rooted, and may be used to replace alfalfa when the prevalence of dwarf disease makes the growing of alfalfa no longer profitable or possible.

Kearney and Scofield (12) stated that strawberry clover, "is as tolerant of salinity as most of the native or introduced grasses, or even more tolerant". Ahi and Powers (1), working with sand and solution cultures, found that alfalfa and strawberry clover would tolerate 2,800 and 5,600 p.p.m. of salt obtained by diluting sea water, respectively. They concluded that, "strawberry clover was found the most promising resistant legume for salinity, followed by sweet clover, then alfalfa".

The Bureau of Plant Industry and others have made several introductions of strawberry clover and a number of strains have since been identified in the states ranging from Washington to Colorado. A comparison of some of these strains for their tolerance to salinity was suggested.[4] In order to compare the behavior of strawberry clover under saline conditions with other legumes, alfalfa and Ladino clover were included in these tests.

Alfalfa is the most widely grown forage crop in the western United States and, as in this study, is commonly included as a standard in tests of forage crops (11). Harris (7) cites considerable data on the tolerance of alfalfa to alkali, giving the maximum salt tolerated equal to 6,000 p.p.m. of sodium sulfate in the soil. More recently, in a survey (17) of salinity conditions in the Pecos River Valley of New Mexico and Texas it was found that alfalfa growing well where the soil solution extracts (extract from a soil at the saturation

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[1]Contribution from the U. S. Regional Salinity Laboratory, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, Riverside, Calif., in cooperation with the eleven western states and the Territory of Hawaii. Received for publication April 26, 1943.

[2]Assistant Physiologist and Director, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 879.

[4]Suggested by Dr. E. A. Hollowell, Senior Agronomist, Division of Forage Crops and Diseases, Washington, D. C.

point) had a conductance ($K \times 10^5 @ 25°$ C) of 800 and contained about 5,000–6,000 p.p.m. of salts in the extract. These salts were usually 50 to 60% sulfates and 30 to 50% chlorides. The soils in this region contain large quantities of gypsum. Harris (7) states further that, "the high resistance of alfalfa may be assigned to its deep feeding habits in many cases, the feeding roots not being in the alkali zone but being in the purer solutions below".

Ladino clover, *Trifolium repens*, var. Ladino, a perennial and a native of Italy, is presumed to be a large form of white clover. This crop is rapidly growing in popularity throughout the United States (2, 3, 10, 11, 14, 18, 19), and for irrigated pastures in California it ranks first in popularity and is being recommended in 37 of the 40 counties (11). The popularity of this plant for pastures rests mainly upon the quantity and quality of forage produced, its ability to recover rapidly following grazing or clipping, and the fact that all of its growth is leafy and succulent rather than stemmy. Though little is known of its salt tolerance, preliminary observations have led to the assumption that it is not a very salt-tolerant crop (11, 14).

## MATERIALS AND METHODS

Selected California Common alfalfa seed was supplied by Dr. B. A. Madson, of the California Agricultural Experiment Station. Ladino clover seed (blue label) was obtained from The Grange Company, Oakdale, Calif. Seed of the following strawberry clover strains was obtained from the Bureau of Plant Industry:

FC No. 22,797 strawberry clover (Nebraska)
FC No. 22,798 strawberry clover (Colorado)
FC No. 22,800 strawberry clover (Washington)
FC No. 22,801 strawberry clover (Idaho)
FC No. 22,802 strawberry clover (Oregon)

Seedlings, 20 days old, were transferred to 5-gallon containers (four seedlings per pot) of automatically-operated sand culture equipment (6). By means of this equipment each pot received 2 quarts of solution once each hour from 7 a.m. to 7 p.m., inclusive, with one additional delivery at midnight. With the daily addition of distilled water into the 5-gallon solution reservoir to replace water lost by evaporation and transpiration, and by means of the frequent irrigations, the plants were subjected to a culture solution almost constant in concentration. Decreases in concentration caused by salt absorption by plants were negligible based on the volume of solution used.

*Experimental design.*—Studies made at the Regional Salinity Laboratory (5, 8, 15) have indicated that the reduction of plant growth in saline substrates is better correlated with the osmotic concentration of these substrates than with any other index of concentration. Accordingly this basis was chosen to represent the concentration of solutions in the present experiment. Besides a base nutrient treatment of 0.5 atmosphere osmotic concentration, three additional treatments of 2.5, 3.5, and 4.5 atmospheres were obtained by the addition of sodium chloride to the base nutrient solution.

For alfalfa there were three replications and for Ladino clover and each strain of strawberry clover two replications. There were 10 pots per table, and treatments were randomized on the six tables.

*Culture solutions.*—The composition of the culture solutions is given in Table 1.

TABLE 1.—*Composition of the culture solutions.**

| Osmotic concentration, atmospheres | Ca | Mg | Na | K | Cl | $SO_4$ | $H_2PO_4$ | $NO_3$ | $HCO_3$ | $K \times 10^5$ @ 25°C |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Equivalents per million† | | | | | |
| 0.5 (base nutrient) | 5.9 | 2.7 | 2.1 | 3.25 | 1.8 | 4.3 | 0.75 | 7.0 | 2.1 | 154 |
| 2.5 | 5.9 | 2.7 | 50.1 | 3.25 | 49.8 | 4.3 | 0.75 | 7.0 | 2.1 | 662 |
| 3.5 | 5.9 | 2.7 | 74.1 | 3.25 | 73.8 | 4.3 | 0.75 | 7.0 | 2.1 | 918 |
| 4.5 | 5.9 | 2.7 | 98.1 | 3.25 | 97.8 | 4.3 | 0.75 | 7.0 | 2.1 | 1,142 |
| | | | | | Parts per million | | | | | |
| 0.5 (base nutrient) | 118 | 33 | 47 | 128 | 64 | 20 | 74 | 434 | 129 | 154 |
| 2.5 | 118 | 33 | 1,152 | 128 | 1,766 | 20 | 74 | 434 | 129 | 662 |
| 3.5 | 118 | 33 | 1,704 | 128 | 2,617 | 20 | 74 | 434 | 129 | 918 |
| 4.5 | 118 | 33 | 2,256 | 128 | 3,468 | 20 | 74 | 434 | 129 | 1,142 |

*Micro-elements were added to all solutions as follows: Boron, 0.5 p.p.m. from boric acid; manganese, 0.5 p.p.m. from manganese chloride; and, iron, 0.5 p.p.m. from ferric citrate. The tap water used in making up solutions was alkaline, but the inclusion of nitric acid in the composition of the solution reduced the pH to an initial value of 5.7.

†"An equivalent per million (e.p.m.) is a unit chemical equivalent weight of solute per million unit weights of solution. Concentration in equivalents per million is calculated by dividing concentration in parts per million (p.p.m.) by the chemical combining weight of the substance or ion. This unit has also been called 'milli-equivalents per liter' and 'milligram equivalents per kilogram.' The latter term is precise, but the former will be in error if the specific gravity of the solution is not exactly 1.0." A.S.T.M. Standards, 1940; part III, page 541.

From April 27 until May 23, 1942, all pots received only base nutrient solution. On May 23, 46 days after seeding, the alfalfa was cropped for it had attained a height of 35–40 cm and was at the incipient flowering stage. Following this cropping of alfalfa, there was a removal and replenishment of two-thirds of the base nutrient solution in all units. After a lapse of 3 days to permit some recovery following cutting, salt treatment on all crops was initiated. Starting on May 26 the solutions were brought up to final concentration at the rate of 1 atmosphere osmotic concentration of sodium chloride per day.

*Insect control.*—The greenhouse was fumigated with Nicofume on May 7 and June 3, 1942, to control thrips on alfalfa. Although the fumigation was intense enough to produce some visible symptoms of injury to the plants, the thrips were not fully eradicated on the alfalfa.

*Harvesting procedure.*—Plants were harvested at incipient to early flowering stage. Alfalfa was cut 4 inches from the level of the sand, while the Ladino and strawberry clovers were cut off even with the top of the pot or container, i.e., at about the 1½- to 2-inch level. Immediately after harvesting and weighing, the plants were dried rapidly in a large, forced-draft, gas-heated oven and oven-dry weights were obtained.

## TREATMENT OF HARVEST DATA

One of the most important considerations in a comparison of forage crops is total production of a forage within a growing season. Therefore, although there were three croppings of alfalfa (May 23, June 15, and July 13, 1942) and two croppings of the clovers (June 15 and July 13, 1942) during the elapsed time of the experiment (97 days), only the total yield for the "season" is reported.

This basis is also preferable owing to the fact that different crops reach their peaks in the production of forage after different lengths of time.

Owing to differences in moisture contents of the species studied, the yield data are given on the dry weight basis. The percentage dry matter in the tops was within the range expected for each of the three species studied and, with increase in the salt concentration of the substrate, the percentage dry matter in the tops tended to increase. Alfalfa showed this trend at the time of the first harvest, but at the second harvest there was no consistent trend in the percentage dry matter with treatment. At the second harvest the tops of alfalfa contained approximately 23.5% dry matter. At this later harvest, the tops of the strawberry clover strains from any one treatment had very similar percentages of dry matter, averaging 16.7, 18.3, 20.1, and 21.5 for the treatments 0.5 (B.N.), 2.5, 3.5, and 4.5 atmospheres osmotic concentration, respectively.

In the same order ot treatments the values for Ladino clover were 16.7, 19.0, 20.3, and 22.6% dry matter, respectively. It is reported in the literature that the addition of sodium chloride to the substrate resulted in an increase in the dry matter content of barley tops (4), a decrease in that of tomato tops (8), and no change in the dry matter of tops of dwarf red kidney bean (20).

Yield data may be interpreted on an "actual weight basis" or on a "relative weight basis" in which the growth of each crop under the base nutrient treatment is taken as 100%. From an agronomic point of view the principal consideration is total weight of forage produced. However, with crops of diverse weights such as these the yield data must be converted to the relative basis in order to determine the differential response of the various crops and strains to a given series of treatments. Thus, both bases are useful and both will be used in the following discussion.

Owing to the more rapid early growth of alfalfa, there was a pre-salt treatment harvest on the 46th day of the experiment, May 23, 1942, which yielded 9.28 grams of dry matter per pot (standard error, 0.25 gram). This weight is not included in any of the following data inasmuch as all pots were still receiving only base nutrient solution at this time.

Harvest weights are based on the average yield per pot of four plants for the entire experimental period.

## RESULTS

Combined dry weights of tops produced by the various crops at the different salt levels are shown in Table 2.

Pictures were taken of the crops just prior to the final harvest. The various strains of strawberry clover were so similar in appearance that the picture of the highest yielding Nebraska strain alone is shown, together with alfalfa and Ladino clover (Fig. 1).

## DISCUSSION OF RESULTS

The principal purpose of this experiment was to compare the tolerance of various strawberry clover strains to salinity. In the selection of a forage crop for use on saline land, tolerance to salinity is necessary. Usually, salty lands have a high water table and may be water-logged. In addition to salinity tolerance the crop must often be able to withstand water-logged conditions. It is believed that strawberry clover has achieved its popularity because it is

moderately tolerant to salinity and in addition is highly tolerant of a high water table. In our greenhouse tests the experiment was not designed to test the latter factor.

TABLE 2.—*Dry weight in grams of tops of strawberry clover, alfalfa, and Ladino clover produced during 97 days of growth, April 7 to July 13, 1942.*

| Osmotic concentration, atmospheres | 0.5 (B.N.) | 2.5 | 3.5 | 4.5 | Strain or crop mean* |
|---|---|---|---|---|---|
| Strawberry clover strains: | | | | | |
| Nebraska | 45.6 | 43.3 | 34.8 | 28.9 | 38.1 |
| Idaho | 45.6 | 40.5 | 27.5 | 22.4 | 34.0 |
| Colorado | 41.1 | 32.5 | 27.4 | 22.7 | 30.9 |
| Washington | 41.6 | 33.0 | 25.1 | 15.7 | 28.8 |
| Oregon | 36.8 | 30.6 | 24.3 | 19.4 | 27.7 |
| Alfalfa† | 61.1 | 45.4 | 38.9 | 32.8 | 44.5 |
| Ladino clover | 96.3 | 64.8 | 55.4 | 42.7 | 64.8 |

*Difference between any two mean weights of strawberry clover strains needed for significance at the 5% level, 4.22 grams; for significance at the 1% level, 5.76 grams.

†A pre-salt treatment harvest of 9.28 grams dry weight was made. This is not included in the totals of this table.

## INTERCOMPARISONS OF STRAWBERRY CLOVER STRAINS

*Dry weight of tops.*—On the basis of actual yields, the Nebraska strain yielded significantly better than the Colorado, Washington, and Oregon strains, but its yield did not differ significantly from that of the second best Idaho strain. It is also evident from Table 2 that there was a highly significant difference in yield between any two treatments with the higher yield always in favor of the treatment with the lower concentration of salt.

*Relative dry weight of tops.*—Inasmuch as some strains made better growth than others under the base nutrient treatment, relative dry weights were calculated for comparing the response of the strains to salt treatment. On the relative basis there was a significant difference in yield only between the highest and lowest yielding strains, *viz.*, Nebraska *vs.* Washington.

## INTERCOMPARISONS AMONG THREE HIGHEST YIELDING STRAINS OF STRAWBERRY CLOVER, ALFALFA, AND LADINO CLOVER

An average of yields from all treatments on an actual weight basis (Table 2) shows that alfalfa yielded 1.3 and Ladino clover 1.9 times as great a weight of tops as strawberry clover (average for the three highest yielding strains). These results are in agreement with the field observations on these crops as reported by Jones and Brown (11). They have observed that, except under certain special conditions, Ladino clover outyields strawberry clover, and that under conditions where Ladino clover does not survive, strawberry clover usually makes only a very sparse growth. From June 15 to July 13, 1942, the daily temperatures in the greenhouse were comparatively high (maximum daily temperatures averaging around 99° F), and there was undoubtedly a "lag" in the growth of the Ladino clover, as has been reported by Jones and Brown (11) for the growth of Ladino clover during

hot weather. They report that alfalfa is relatively unaffected by such periods of hot weather. However, despite the "relative" depression in the growth of this crop as compared with alfalfa and strawberry clover, on an actual yield basis Ladino clover yielded the greatest amount of forage.

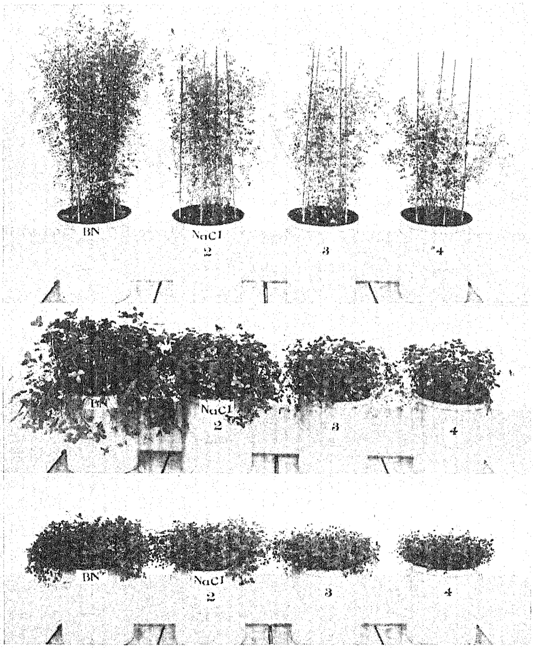


FIG. 1.—Appearance of plants at time of final harvest, July 13, 1942; 97 days from date of seeding. *Top*, alfalfa; *center*, Ladino clover; *bottom*, Nebraska strawberry clover. BN = base-nutrient; 2, 3, and 4 = number of atmospheres osmotic concentration of sodium chloride added to the base-nutrient solution.

*Relative dry weight yields.*—The relative dry weights of tops for the three best strains of strawberry clover, Nebraska, Idaho, and Colorado, and for alfalfa and Ladino clover are shown graphically in Fig. 2.

In preparing Fig. 2 data for the Washington and Oregon strains of strawberry clover were omitted so as not to make the graph too confusing. In a statistical comparison, including these two strains, the only significant difference in response at the 5% level was between the Nebraska strain and Ladino clover.

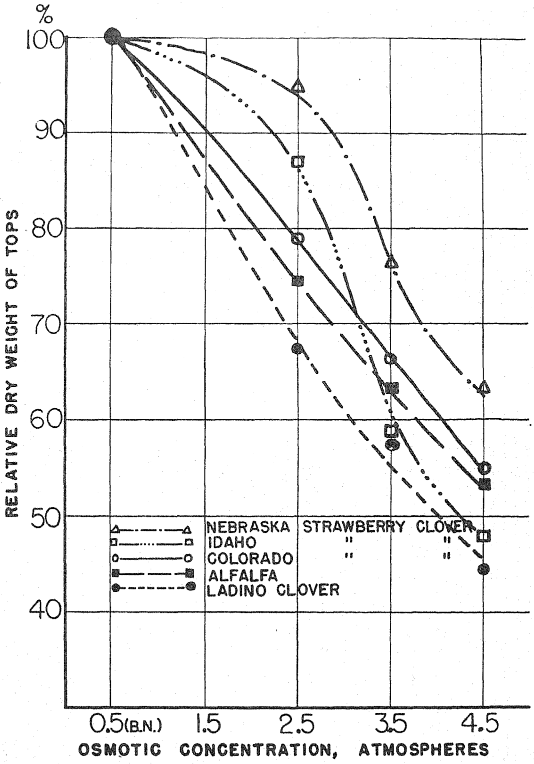


FIG. 2.—Relative dry weight of tops produced by the various strains of strawberry clover, alfalfa, and Ladino clover.

On a treatment mean basis involving the three best strains of strawberry clover, alfalfa, and Ladino clover, statistical analysis of the data showed that each increment of salt very significantly reduced the yield of tops.

## RELATIONSHIP OF TESTS TO PRACTICAL AGRICULTURE

In view of the present demand for an increase in livestock production it seemed especially pertinent to study the response of several of the most important forage crops to salinity *per se*. In the selection of a forage crop, tolerance to salinity is, of course, only one of several important considerations. For example, it is generally agreed that one of the main virtues of strawberry clover is its ability to withstand not only a moderate amount of salinity but also a high water table and a water-logged condition of the soil. Our results show that *on a relative basis* only one of the five strains of strawberry clover, the Nebraska strain, was less affected by salt than either alfalfa or Ladino clover. However, despite the greater, relative salt effect on alfalfa and Ladino clover, *on an actual weight basis* these two crops yielded 1.3 and 1.9 times more forage, respectively, than did strawberry clover. Therefore, unless there are other important factors to consider such as unfavorable soil conditions, wherever Ladino clover or alfalfa can be established, these crops would generally be preferable to strawberry clover. The choice between alfalfa and Ladino clover rests on certain characteristics of the soil in question. Madson and Coke (14) state that in California alfalfa will usually outyield Ladino clover on the deeper and more porous soils, while on the more shallow and heavier soils Ladino will usually outyield alfalfa.

Recently, Magistad and Reitemeier (16) studied 17 representative western soils to determine the range of soil solution concentration and composition, and correlated these values with the observed plant growth. By means of the particular technic which they used, it was possible to obtain soil solutions at soil moisture contents near the wilting range, and possible errors in concentration and composition brought about by extrapolation back to field moisture contents were minimized if not altogether eliminated. Their data show the relationship between plant growth and soil solution concentrations in the wilting range. They give data showing that the concentration of soil solutions of saline soils may reach values of 40 atmospheres or more. At concentrations above three atmospheres plant growth was affected.

The range of salt concentrations used in the present study compare with concentrations of salt found in the soil solution of slightly saline soils by Magistad and Reitemeier (16).

## SUMMARY

The relative yields and tolerances of five strains of strawberry clover, alfalfa, and Ladino clover to serial increases in the concentration of salt (NaCl) in the substratum were determined. The

concentration of the nutrient solution in the sand culture ranged from 0.5 to 4.5 atmospheres. The following results were obtained:

1. On an *actual yield basis*, alfalfa and Ladino clover yielded 1.3 and 1.9 times as much forage, respectively, as strawberry clover.

2. On a *relative basis* the Nebraska strain of strawberry clover was less affected by salt than alfalfa or Ladino clover. The differences in favor of the Colorado and Idaho strains and of alfalfa over Ladino clover approached significance at the 5% level.

3. Of the five strains of strawberry clover tested, the Nebraska strain yielded significantly better than the Colorado, Washington, and Oregon strains, but was not superior to the second highest yielding strain (Idaho).

4. On both the actual and relative yield bases there was a highly significant difference in yield between treatments, with the higher yield always in favor of the treatment with the lower concentration of salt.

5. There was no evidence that there is a given concentration of solution which may be regarded as critical, but rather there tended to be a linear relationship between growth reduction and increase in salt concentration of the solutions as expressed in atmospheres.

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# ICE SHEET INJURY TO ALFALFA[1]

M. A. Sprague and L. F. Graber[2]

ICE sheets which form and remain for extended periods in contact with the soil and crowns of alfalfa, clovers, and winter grains are among the most injurious of the climatic factors influencing the winter survival of such crops. The injuries may not only be severe, but they may occur over very wide areas. Ice sheets which are limited to local areas such as low spots in fields are of rather common occurrence, but sleet storms causing ice sheets over extensive areas are much less frequent in Wisconsin.

In February, 1937, sleet storms developed sheets of ice which covered most of the southeastern third of Wisconsin. Wall (8)[3] obtained information from 500 farmers in this ice-coated region as to the nature and duration of the ice sheets and the resulting losses in terms of the survival of alfalfa fields. He found that the stands on 237,000 acres (about one-fifth of the total acreage of Wisconsin) were thinned and injured to a degree as to be no longer of practical value for hay. Most of such losses developed in areas where ice formed and persisted for 20 days or more in direct contact with the soil surface and the exposed parts of the crowns of alfalfa. Losses were much lower where the ice crust was porous and where a layer of snow prevailed between the ice sheet and the soil. In February, 1922, a similar but less extensive sheet of ice in this same general area resulted in the loss of 40,000 acres of alfalfa which constituted about one-fourth of the total acreage of the state at that time.

## REVIEW OF LITERATURE

Although ice sheets may be serious factors in the winter survival of alfalfa and other over-wintering crops, little work has been done to ascertain the causal aspects of such injury. A recent monograph by Levitt (6) gives a critical review of the literature on frost killing and hardiness, and the well-known bibliography of low temperature relations of plants by Harvey is very inclusive. The authors, however, have found very little literature pertaining to the fundamental factors involved in ice-sheet killing.

Bugaevskii and Zitnikova (2) mentioned ice as a cause of killing in 1936 when they reported death of wheat plants after 54 days beneath an ice crust and suggested a lack of oxygen as the factor involved. Brierley, *et al.* (1) coated dormant strawberry plants with clear ice and noted internal carbon dioxide increases up to 24% and oxygen decreases to as low as 4% during three weeks at tempera-

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[3]Figures in parenthesis refer to "Literature Cited", p. 893.

tures of −1° to −6° C. However, they attributed the greater share of winterkilling from ice contacts in the field to properties of greater thermal conductivity which would make the effects of low temperature more pronounced.

Sprague and Graber (7) began studies on the causal aspects of ice-sheet injury of alfalfa in 1933. They observed that the formation of ice in contact with the roots and crowns of hardy alfalfa plants was not in itself injurious or lethal, but that the duration of ice contact determined the extent of the injury sustained. Their trials, in which hardened alfalfa roots and crowns were stored in water, ice, and various gaseous media, were designed to determine the effects of the surrounding storage conditions upon survival. Only non-injurious temperatures of storage from 1° to −4°C were used. Pure carbon dioxide in closed test tubes proved to be very injurious as a storage medium. Moreover, carbon dioxide was assumed to accumulate in sufficient quantities as a respiratory product in closed containers of air, water, and other media to reach toxic concentrations contributing to the observed injury. When plants were stored in atmospheres designed to remove excess carbon dioxide or to prevent its accumulation, such as flowing air, flowing nitrogen, and air bubbled through water, they suffered much less injury than plants confined for similar periods in ice, still water, still nitrogen, still carbon dioxide, flowing carbon dioxide, and carbon dioxide bubbled through water. With the exception of those stored in solid cakes of ice, cold-hardened alfalfa plants maintained in a water medium through which carbon dioxide was bubbled suffered the most rapid and intense injury of those in any of the storage media employed. Plants stored in closed containers of still nitrogen were injured somewhat more severely than in still air and oxygen deficiencies were regarded as being associated with the accumulations of the products of anaerobic respiration.

The injurious effect of carbon dioxide as an external medium is not a recent observation. As early as 1804, Saussure, cited by Clements (3), observed that growing chestnut plants, whose roots were stored in carbon dioxide, died in 7 to 8 days, while those stored in air were still vigorous at the end of three weeks. Corenwinder, also cited by Clements (3), found that marsh plants died quickly when their roots were submerged in water charged with carbon dioxide. Free (4) observed the same relation in buckwheat.

## EXPERIMENTAL WORK

The investigations reported in this paper were begun in October, 1936, and are a continuation of the studies begun by Sprague and Graber (7) in 1933. Some of the previous trials were repeated and additional experiments were designed to determine further the role of carbon dioxide and other factors thought to be immediately associated with ice-sheet injury to alfalfa.

All trials were conducted in the laboratory with seedling plants of alfalfa grown in the field, and in most instances they were cold hardened there. The temperature chamber consisted of an ammonia-cooled box regulated to provide temperatures not lower than −4° C. A 25-gallon water bath built into one end of the cold box and cooled by a freezing unit from the ammonia system was held at 1° C. Subsequent to storage treatment, the samples of dormant alfalfa plants from the cold box were submerged in the cold water bath during the time necessary for slow thawing, after which all samples were removed to the greenhouse and transplanted in quartz sand. The dry weight of top growth produced during a period of 3 weeks under continuous illumination was used as the index of the injury

inflicted during the preceding storage period. The selection of quartz sand, in preference to soil, in which to transplant and observe growth was considered more advantageous from the standpoint of providing more uniform growing conditions and relying entirely upon the resources of the treated plant for growth recovery.

## RESULTS

### SURVIVAL AS INFLUENCED BY STORAGE MEDIA (EXPERIMENT 1)

On October 12, 1936, healthy 1-year-old Turkestan alfalfa plants were brought into the laboratory from the field and, after a hurried washing in cold tap water, were wrapped in moist towels and stored in the cold box at 5° C. On October 20, they were removed and trimmed to a length of 5 cm from the cotyledonary region upward and 10 cm from the same region downward. Selecting the plants as nearly as possible for uniformity of root and crown, 20 samples were sorted out, each composed of 10 plants. Five of the samples were placed in quart-size ice cream containers and frozen in solid blocks of ice. Five more were placed in tightly sealed 80 cc pyrex test tubes with air as the surrounding medium. Each of the 10 remaining samples was placed in a 980-cc glass jar filled with tap water. Five of these jars were fitted with rubber stoppers, care being taken to expel all of the air possible when inserting the stopper. The remaining five were provided with delivery tubes and, by means of a series arrangement, precooled tap water was circulated over the roots at a rate of 60 cc per minute. The samples in still or flowing water were placed in the water bath at 1° C; those in ice and still air were placed in the cold box at -3° C. Samples were removed from storage at successive intervals of 10 days during a 60-day period. Those stored in ice were thawed for 8 hours in air at 1° C, after which all of the samples were transplanted in the greenhouse for a 3-week period of growth.

The oven-dried weights of top growth produced during 3 weeks in the greenhouse (Table 1) by each of the samples of 10 plants were used as a basis for determining the degree of injury from previous storage in various media. Since light, temperature, and other growth factors varied from one period to another, the dry weight data, as

TABLE 1.—*Grams of oven-dry top growth produced in the greenhouse by young alfalfa plants following periods of storage in water, air, and ice.**

| Days of storage | Running water | | Still water | | Still air | | Ice | |
|---|---|---|---|---|---|---|---|---|
| | Dry weight, grams | Recovery, % | Dry weight, grams | Recovery, % | Dry weight, grams | Recovery, % | Dry weight, grams | Recovery, % |
| 10 | 4.88 | 100 | 2.48 | 50.8 | 2.92 | 59.8 | 0.59 | 12.0 |
| 20 | 4.55 | 100 | 2.92 | 64.1 | 1.82 | 40.0 | 0.00 | 0.0 |
| 30 | 7.13 | 100 | 0.72 | 10.1 | 1.97 | 27.6 | 0.00 | 0.0 |
| 40 | 6.23 | 100 | 0.72 | 11.6 | 2.02 | 32.4 | 0.00 | 0.0 |
| 60 | 4.57 | 100 | 0.00 | 0.0 | 0.02 | 0.5 | 0.00 | 0.0 |

*Experiment I, series of October 20 to December 19, 1936. Storage in water was at 1° C and in air and ice at -3° C.

such, do not give an adequate comparison for the effects of the various storage treatments. Consequently, the percentage of recovery is calculated on the basis of 100 for all samples stored in circulating water which had a complete survival for all periods of storage and later made a vigorous growth.

The alfalfa plants used in this trial were but partially cold-hardened as taken from the field. Those stored in blocks of ice were first to show severe injury and were the only ones where the loss in survival was 100% with a storage period of 20 days. They were followed in order by the injury sustained by samples stored in still water and still air. The samples surrounded by a constant flow of water showed no evidence of injury during the entire period of 60 days of storage. These data support the hypothesis that waste products produced during dormancy are carried off adequately by flowing water to prevent injury; whereas, when plants are confined in closed containers of water, such respiratory products eventually reach toxic concentrations. The injuries sustained from storage in still air were less than those in still water even though the samples of alfalfa plants were confined in 80-cc test tubes of air as compared with 980-cc jars for the plants stored in water. With alfalfa plants frozen in blocks of ice, the opportunity for the diffusion and removal of waste products was extremely small and apparently their internal accumulations and pressures were determining factors resulting in the death of all plants during 20 days of such storage.

### EFFECT OF STORAGE IN CLOSED CONTAINERS OF VARIOUS SIZES (EXPERIMENT II)

On November 12, 1938, after several hard frosts, several thousand plants of Grimm alfalfa 3½ months of age were dug from the field, selected for uniformity, "heeled in" in the field in bunches of about 250, and covered with straw. This provided a convenient supply of hardened plant material throughout the winter season. On December 17 about 500 of the hardened plants were brought into the laboratory, washed, trimmed to root lengths of 10 cm and crown lengths of 5 cm, as in experiment 1, and grouped into uniform samples of eight plants each. In this experiment 10 samples were stored in large-mouth jars of approximately 980 cc capacity and 10 more were stored in test tubes of 80 cc capacity. Five of the test tubes and five of the jars were filled with tap water, tightly fitted with solid rubber stoppers, and placed in the water bath for storage at 1° C. The remaining five jars and five tubes were tightly stoppered with air as the surrounding medium and were stored in the cold box at −3° C. The measurements of recovery in the greenhouse, made as before, are presented in Table 2.

Whether in air or water, plants confined in large jars survived storage much longer and were more vigorous following any single storage period than were plants confined to the test tubes of much smaller capacity. Water was more detrimental as a storage medium than air.

Respiratory products of the alfalfa, associated microorganisms, or both, accumulated in one of the test tubes containing still water

to the extent that sufficient pressure was developed to blow out the stopper. The stoppers of the remaining tubes were promptly wired into place to prevent further loss, but upon opening them at a later date the sudden release of pressure induced a noticeable amount of effervescence. That the escaping gas consisted primarily of carbon dioxide was verified by precipitation with barium hydroxide. The exact amounts were not determined, but it was observed that large quantities of gaseous by-products of respiration had been released by the dormant plants stored at 1° C. Assuming the respiration of replicate plant samples to be nearly equal, the respiratory products would be expected to reach higher concentrations more quickly in the small tubes than in the larger jars.

TABLE 2.—*Grams of oven-dry top growth produced by hardy Grimm alfalfa plants during 3 weeks in the greenhouse following storage in closed large and small containers of water and air at 1° C and −3° C, respectively.**

| Days of storage | Storage in water at 1° C | | Storage in air at −3° C | |
|---|---|---|---|---|
| | Test tubes (80 cc) | Jars (980 cc) | Test tubes (80 cc) | Jars (980 cc) |
| 0 | 1.24 | 1.24 | 1.24 | 1.24 |
| 15 | 1.58 | — | — | — |
| 20 | 1.15 | 2.31 | — | — |
| 25 | 0.24 | — | — | — |
| 30 | 0.00 | 0.72 | — | — |
| 32 | — | — | 0.03 | 0.42 |
| 36 | — | 0.56 | — | — |
| 40 | — | — | 0.00 | 1.10 |
| 46 | — | 0.00 | 0.00 | 0.10 |
| 61 | — | 0.00 | 0.00 | 0.44 |
| 75 | — | — | 0.00 | 0.00 |

*Experiment II, series of December 19, 1938 to March 5, 1939.

CARBON DIOXIDE PRODUCTION DURING STORAGE (EXPERIMENT III)

The plants used in experiment III were taken from the same field which provided the plant material for experiment II. They were removed from the field on April 25, 1939, just as the spring growth was beginning to be evident. After 4 days in the cold box at 2° C, 12 samples of 10 plants each were placed in 12 33×300 mm test tubes, 6 of which were filled with nitrogen and 6 with air as the surrounding media. Each tube was provided with a two-hole rubber stopper and delivery tubes, to the exposed ends of which were attached rubber unions and screw pinch clamps. Storage in still air and still nitrogen was in the cold box at −3° C and removal from storage was at weekly intervals. After thawing for several hours at 1° C, each closed tube in turn was fitted into a modified respiratory apparatus and carbon dioxide-free air was passed over the roots until the accumulated carbon dioxide was removed and determined quantitatively. The calculated concentrations of carbon dioxide in grams per liter of surrounding storage media and the oven-dry weights of top growth produced by each sample during 3 weeks growth in the greenhouse are presented in Table 3.

TABLE 3.—*Growth recovery and concentrations of accumulated carbon dioxide from alfalfa plants previously stored for 0 to 35 days at −3° C in nitrogen and in air.**

| Days of storage | Storage in air | | Storage in nitrogen | |
|---|---|---|---|---|
| | Dry weight of top growth, grams | Conc. of $CO_2$, grams per liter | Dry weight of top growth, grams | Conc. of $CO_2$, grams per liter |
| 0 | 1.58 | 0.0422 | 1.58 | 0.0422 |
| 7 | 0.74 | 0.2578 | 0.63 | 0.1822 |
| 10 | 1.16 | 0.2335 | 0.92 | 0.1835 |
| 14 | 1.34 | 0.3622 | 0.63 | 0.2187 |
| 21 | 0.44 | 0.4956 | 0.24 | — |
| 28 | trace | 0.3609 | trace | 0.2483 |
| 35 | 0.08 | 0.3817 | 0.11 | 0.5217 |

*Experiment III, series of April 29 to June 2, 1939.

In atmospheres of both air and nitrogen little injury was inflicted upon stored plants during the first 14 days. The concentration of carbon dioxide surrounding the roots increased with the duration of the storage period and there was a corresponding increase in the injury sustained by the plants (Fig. 1). After storage all of the samples were observed to have liberated in excess of 100 mg of carbon dioxide, indicating that even at −3° C considerable activity occurs. The presence of oxygen in the tubes containing air appeared to permit a more rapid respiratory rate as indicated by the greater carbon dioxide liberations. However, injury was experienced sooner by plants stored in nitrogen, though the amounts of carbon dioxide produced were considerably less than those produced by the plants stored in air. This suggests that the products of anaerobic respiration may have been very toxic.

## EFFECT OF CARBON DIOXIDE CONCENTRATION UPON SURVIVAL (EXPERIMENT IV)

Early in June, 1939, nonhardened Grimm alfalfa plants were obtained from the same field which provided material for experiments II and III. They were washed and trimmed as before, wrapped in wet towels, and placed in the cold box at 2° C for 12 days. At the end of that time 25 samples of 10 plants each were selected and placed into 25 33×300 mm pyrex test tubes. Five series of five tubes each were provided with delivery tubes and rubber unions and arranged in a series. Each of the five series was provided with one of five concentrations of carbon dioxide in flowing air as follows: 50%, 25%, 10%, and 5% carbon dioxide in air by weight and carbon dioxide-free air. The carbon dioxide-free air was prepared in the laboratory by passing air from the laboratory jet over soda lime and bubbling through barium hydroxide. The other four media were mixed in gas cylinders at 100 atmospheres of pressure from commercial supplies. The flow of gas was regulated in each case to from 5 to 6 bubbles per second and all samples were placed in

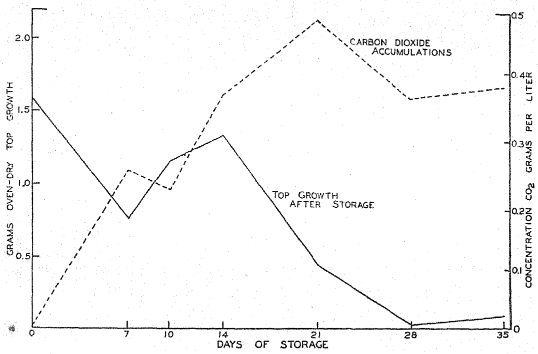


FIG. 1.—Top growth after storage and accumulations of carbon dioxide from 10 samples of Grimm alfalfa plants stored in test tubes with air as a surrounding medium. Temperature during storage was maintained at -3° C. Experiment III, series of April 29 to June 2, 1939.

the cold box at 1° C. At several intervals of storage, samples from each series were transferred to favorable conditions for growth in the greenhouse.

The weights of oven-dry top growth produced during the recovery period are presented in Table 4. Plants stored in atmospheres of 10%, 5%, and 0% carbon dioxide survived 35 days of storage very well and were only moderately weakened after 54 days of storage. Samples surrounded by 25% and 50% carbon dioxide were seriously weakened after 21 days and were dead after 54 days of storage. Plants pictured in Fig. 2 show the manner and extent of recovery following the storage conditions of this experiment.

In this experiment known concentrations of carbon dioxide were provided in flowing atmospheres. The injury inflicted during storage

TABLE 4.—*Growth recovery of 10 plant samples of Grimm alfalfa stored for 0 to 54 days in various concentrations of carbon dioxide in flowing air at 1° C.**

| Days of storage | Grams of oven-dry top growth produced by 10 plants stored in | | | | |
|---|---|---|---|---|---|
| | 50% $CO_2$ | 25% $CO_2$ | 10% $CO_2$ | 5% $CO_2$ | $CO_2$-free |
| 0 | 2.15 | 2.15 | 2.15 | 2.15 | 2.15 |
| 11 | 1.60 | 1.69 | 1.78 | 1.34 | 1.04 |
| 21 | 0.65 | 0.72 | 2.01 | 2.08 | 1.52 |
| 27 | 0.18 | 0.30 | 2.66 | 1.27 | 1.54 |
| 35 | 0.13 | 0.45 | 1.16 | 1.27 | 1.09 |
| 54 | 0.00 | 0.00 | 0.71 | 0.92 | 0.70 |

*Experiment IV, series of June 17 to August 11, 1939.

clearly indicates the detrimental effects of high concentrations of carbon dioxide. The data indicate (Table 4), however, that carbon


FIG. 2.—Relative growth of Grimm alfalfa plants during 3 weeks in the greenhouse following 35 days (A) and 54 days (B) of storage. From left to right are pictured samples stored in 50%, 25%, 10%, 5%, and 0% carbon dioxide in flowing air. Temperature during storage was maintained at 1° C. Experiment IV, series of June 17, to August 10, 1939.

dioxide is not lethal unless external concentrations are maintained for a considerable length of time. Plants surrounded by air containing 50% carbon dioxide required 3 weeks to show severe weakening rather than a few days or hours as might be expected if the gas itself were directly toxic. This suggests that high external concentrations of carbon dioxide may favor the production of compounds in the plant tissue which are directly toxic.

The plants stored in the carbon dioxide-free medium were injured more severely than those stored in either 5% or 10% mixtures of the gas, but were not injured nearly as much as those samples stored in 25% or 50% mixtures. Further evidence of the injuries from storage in carbon dioxide-free air was observed in experiment V.

### EFFECTS OF THE PRESENCE AND ABSENCE OF $CO_2$ AND $O_2$ (EXPERIMENT V)

On January 4, 1940, 380 hardened Grimm alfalfa plants 5 months of age were brought into the laboratory and arranged into 38 samples of 10 plants each. Twenty of these samples were placed in large pyrex test tubes fitted with one-hole rubber stoppers into which were fitted glass stopcocks. The stopcocks were opened daily during storage just long enough to release any pressure which might have developed but not sufficiently to allow any appreciable gaseous exchange. A small vial of 5% potassium hydroxide was placed in the bottom of each of five of the test tubes to remove the $CO_2$ from the surrounding atmosphere whether originally contained in the medium or later liberated by the plants as a product of respiration. Oxygen was present in these tubes ($-CO_2+O_2$) as a component of the air. Five more tubes ($+CO_2$ $-O_2$) were filled with an atmosphere from which the oxygen had been removed and in which carbon dioxide was allowed to accumulate during storage. The atmospheres within another five tubes were kept devoid of both carbon dioxide and oxygen ($-CO_2-O_2$) throughout the storage period by inserting a small vial of potassium pyrogallate into each tube. The remaining five tubes ($+CO_2+O_2$) were provided with air as the surrounding medium and carbon dioxide was allowed to accumulate as a product of respiration. In addition, five samples were frozen in solid blocks of ice, five more were wrapped loosely in wet towels, and five were placed in stoppered and sealed test tubes of air ($+CO_2+O_2$). All samples were placed in the cold box at $-4°$ C. Three untreated (check) samples were immediately transplanted in sand for growth in the greenhouse. Samples from each series under treatment were removed from the cold box at intervals of about 5 days, allowed to thaw several hours at 1° to 2° C and were then planted in the greenhouse.

Oven-dry weights of the top growth produced by the samples during 3 weeks in the greenhouse, including the check samples not stored, are presented in Table 5 as measures of the injury inflicted during storage. In this experiment, storage periods were considerably shortened from those of previous experiments and atmospheric pressures were maintained in most instances. The plant material used was high in reserves and in cold hardiness and in some cases survival was

TABLE 5.—*Oven-dry top growth produced by Grimm alfalfa during 3 weeks in the greenhouse after storage in test tubes containing various media for periods of 0 to 32 days at -4° C.**

| Days of storage | Grams of oven-dry top growth produced following storage in | | | | | | |
|---|---|---|---|---|---|---|---|
| | Atmospheric pressure | | | | | Increased pressure | |
| | Open-air check | $+CO_2-O_2$ | $-CO_2+O_2$ | $-CO_2-O_2$ | $+CO_2+O_2$ | $+CO_2+O_2$ | Ice |
| 0 | 1.82 | 1.82 | 1.82 | 1.82 | 1.82 | 1.82 | 1.82 |
| 7 | — | — | — | — | — | — | 1.97 |
| 10 | 1.08 | 2.26 | 1.68 | 2.19 | 1.75 | 1.85 | — |
| 12 | — | — | — | — | — | — | 1.57 |
| 15 | 1.50 | 1.00 | 2.88 | 1.46 | 1.68 | 0.86 | — |
| 20 | 1.87 | 2.74 | 1.53 | 1.60 | 2.49 | 1.45 | — |
| 26 | 1.76 | 1.56 | 1.27 | 0.54 | 1.68 | 0.75 | 0.00 |
| 32 | 1.82 | 1.60 | 1.17 | 0.00 | 1.55 | 0.71 | 0.00 |

*Experiment V, series of January 6 to February 7, 1940.

considerably higher than in comparable treatments previously reported.

Samples frozen in solid cakes of ice were damaged slightly up to 12 days but were dead following 26 days in the sealed condition, while plants wrapped in wet towels showed no evidence of injury throughout 32 days of storage. With high pressures and concentrations of carbon dioxide developing during storage in ice, the resultant injuries, as might be expected, were much more intense than those which occurred in sealed test tubes of air. Plants stored in atmospheres devoid of either carbon dioxide or oxygen were injured very little throughout the duration of the experiment, with the exception of the unaccountably low value obtained with 15 days of storage without oxygen ($+CO_2-O_2$). However, those plants surrounded by an atmosphere kept devoid of both carbon dioxide and oxygen were severely weakened at 26 days and death had ensued with 32 days of storage even though pressures were normal. With both oxygen and carbon dioxide lacking in the storage medium the severity of the injuries sustained was similar to that of the alfalfa plants sealed in solid blocks of ice. Weights of all samples, determined before and after storage, make it unlikely that the observed killing was due to desiccation through the use of the concentrated and noncontacting absorbing agents. It is suggested that the duration of the respiratory activities of dormant alfalfa plants may be conditioned by the presence of carbon dioxide in an atmosphere devoid of oxygen.

The series of alfalfa samples surrounded by air maintained at atmospheric pressure ($+CO_2+O_2$) suffered no injurious effects (Table 5, column 6), while plants in sealed tubes of air ($+CO_2+O_2$) in which more than atmospheric pressures developed were severely

weakened (Table 5, column 7) after 12 days of storage. Plants of a previous experiment incorporating similar treatments are pictured in Fig. 3.

Close observation of plants after being frozen in solid blocks of ice and stored for from 4 to 5 weeks revealed that the ice in direct contact with the root and crown was the first to melt when exposed to thawing temperatures. As the seal was broken, numerous gas bubbles were observed to escape from the tissue as though they had been

FIG. 3.—Three weeks' recovery of Grimm alfalfa following 40 days of storage at −4° C in (left to right) ice, stoppered tubes of air, tubes of air stoppered to allow for carbon dioxide accumulations but at atmospheric pressure, and check (wrapped in wet towels). Experiment V, series of October 29 to December 7, 1939.

confined under considerable pressure. A drop of barium hydroxide applied to the point of exit produced a white precipitate, indicating that carbon dioxide was present. Increased carbon dioxide pressure during storage would tend to hold more of the carbon dioxide and other by-products in the tissues. Survival was very much improved in experiment II where a larger space was provided around the plants during storage. It would appear that the injury from ice sheets is amplified very considerably by a confined and tightly sealed condi-

tion of the plants. With respiration progressing at the rate suggested in experiment III, pressures considerably higher than atmospheric would be expected within a relatvely short time with alfalfa plants sealed in small containers or especially when frozen in solid blocks of ice.

## DISCUSSION

Ice sheet damage of alfalfa in the field is generally characterized by its totality in that nearly all plants are killed. Differential injury rarely occurs between hardy and less hardy varieties but observations indicate that young, well-established new seedings of hardy varieties of alfalfa are more resistant than older stands of the same varieties. Under field conditions where numerous factors are usually associated with winter injury, it is possible that ice sheets may cause death directly from cold. Ice has a thermal conductivity four times as great as water and about 100 times that of air. It would seem, therefore, that a contacting sheet of ice would provide a much lower degree of insulation than that of air partially entrapped by stubble and other surface residues in the field. The fact, however, that differentials in ice sheet injury between hardy and less hardy varieties are not of common occurrence would indicate that cold is not the dominant factor in ice-sheet damage. Many other field observations support the belief that injury is usually the result of the sealing effect of contacting and enduring formations of ice. For example, alfalfa stands are frequently damaged by late fall or winter applications of coarse lumpy manure. Field studies of such losses have shown that where injury occurred, ice had formed beneath the larger clumps of manure and remained there long after all the snow on the field had melted. It would seem that the manure had insulated the plants (and also the ice), but the contacting ice persisted sufficiently to cause toxic accumulations and pressures of carbon dioxide from the crowns. Similar situations have resulted from ice formation beneath loose bunches of hay remaining in the field and also under the heavy accumulations of top growth from productive stands of alfalfa which were not cut or grazed during the previous growing season. In such instances the plants are well insulated, but the ice formations which are often induced by such excessive vegetative cover persist and become lethal. It is known that cattle in snow-covered fields are not likely to be harmful to stands of alfalfa if the snow is dry and not of such a consistency to be converted to ice by tramping. Such field evidences, while not conclusive, are indicative.

In the trials reported in this paper where the simple effect of cold injury was eliminated, the evidence appears to be quite conclusive that ice injury occurred as a result of the inadequate diffusion of carbon dioxide which, with increasing concentrations and pressures, developed a toxic condition in the plant. More direct measurements of the occurrence of organic acids and other compounds occurring in the tissues during storage in various media are needed to interpret the injury sustained by alfalfa plants.

Determinations of acidity and its possible effect upon the enzymatic activities offer another opportunity to ascertain more speci-

fically the factors involved in toxicity resulting from respiration during storage in various media.


## SUMMARY

The dry weight of top growth produced by transplanted alfalfa during 3 weeks in a greenhouse was used as a measure of the injury sustained from previous periods of storage of dormant plants in various media at harmless temperatures near freezing. The media included still and flowing air, still and flowing water, nitrogen, various concentrations of carbon-dioxide in flowing air, contacting ice, and of carbon-dioxide and oxygen in various ratios and at different pressures.

Dormant, cold-hardened plants frozen and maintained in blocks of ice were weakened after 12 days and all were dead with 20 to 26 days of such storage. Contacting ice was the most injurious of all the storage treatments employed. Circulating water allowed complete survival and vigorous growth after 60 days of storage, while plants confined in still water were weakened after 30 days and all were dead after 60 days at 1° C. Storage in still water was more injurious than storage in still air. Confinement in large containers of either water or air was more conducive to good survival and vigorous growth after any period of storage than confinement in small containers. Storage at pressures higher than atmospheric, resulting from respiration in closed containers, was much more injurious than storage at normal pressures. Measurements of carbon dioxide liberated by dormant alfalfa plants stored in closed test tubes of air or of nitrogen showed a direct relationship between the developing concentrations of the gas and the injury sustained. Although more carbon dioxide was liberated in air than in nitrogen, the injury resulting with the former was usually slightly less, indicating that the products of anaerobic respiration are injurious.

Circulating atmospheres of 25% or 50% carbon dioxide in air produced some weakening at 21, 27, and 35 days and were lethal at 54 days, while plants stored in 0, 5%, and 10% mixtures all showed fair survival and growth after 54 days of storage. Even at the highest concentration a duration of the storage period was required for killing which indicates that external accumulations of carbon dioxide are not directly toxic but that a duration of exposure to the gas may cause internal concentrations of respiratory compounds which are toxic to the cells.

Storage for 32 days in either a carbon dioxide-free or oxygen-free atmosphere provided by absorbing agents was found to be slightly injurious to dormant alfalfa plants, but an intensity of injury similar to that of storage in solid blocks of ice occurred when both carbon dioxide and oxygen were removed by absorption. This suggests that some carbon dioxide was essential for prolonging the respiratory activities of dormant alfalfa plants in the absence of oxygen.


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# EFFECT OF MANGANESE ON THE MICROFLORA AND RESPIRATION OF SOME OREGON SOILS[1]

ALBERT W. MARSH AND WALTER B. BOLLEN[2]

BENEFICIAL effects resulting from the addition of manganese to soils have been in part attributed to its stimulation of the soil microorganisms. These microorganisms in turn create a better root environment, release additional mineral nutrients, and promote increased crop yields. Brown and Minges (2)[3] state that $MnSO_4$ at 100 pounds per acre appreciably increased both ammonification and nitrification. Ammonification but not nitrification may be increased at considerably higher rates. They conclude that, "if a crop responds to moderate applications of $MnSO_4$ or is decreased by larger applications, it may be due to the effect of the manganese on bacterial activity."

Leoncini (6) and Montanari (8) both found that nitrification was increased by small additions of manganese salts.

Deatrich (4) observed that with the addition of manganese, ammonification was stimulated but nitrification reduced.

To investigate these effects further some studies were made on the response of soil microorganisms to added manganese.

## SOILS STUDIED

### SOILS OF THE WILLAMETTE VALLEY

These soils, developed under a mild, humid climate, receive about 40 inches of rainfall annually. They are acid, noncalcareous soils belonging to the brown earth or gray brown podzolic groups.

1. *Chehalis silty clay loam.*—This is a young, moderately heavy, friable, alluvial soil deposited from still water during flood stages. It is a brown earth, very little leached, and is slightly acid in reaction. It possesses good external and internal drainage.

2. *Willamette silty clay loam.*—A mature soil, moderately heavy over a compact subsoil, weathered from old valley fill parent material of basaltic origin. This soil has good external drainage and is moderately acid.

3. *Newberg loamy sand.*—This soil is a brown to light brown, coarse-textured alluvial soil deposited in billows and waves by rapidly moving water. It is frequently subject to overflow, has excessive internal drainage, slightly acid reaction, and low organic matter content.

4. *Melbourne clay loam.*—An upland brown to yellowish brown, moderately heavy residual soil developed on sandstone and shale. It has a moderate supply of organic matter, good moisture retention, and is moderately acid.

5. *Dayton silty clay loam.*—This is a gray to drab, heavy-textured soil. It is developed on the level portions of the valley floor where drainage is poor, the

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[3]Figures in parenthesis refer to "Literature Cited", p. 899.

subsoil is compact and slowly pervious. Because of this it is water logged during a large portion of the year, producing anaerobic conditions and mottling.

PEAT SOILS

1. *Braillier peat.*—This is a coarse, woody, sphagnum peat soil of brown color formed in the marshes of the lower Columbia River Valley. This peat is only slightly decomposed, low in minerals, and strongly leached. It has a pH of 4.1.

2. *Clatskanie peat.*—This is a partially decomposed, grayish brown peat soil of rather high mineral content. It is formed in the Columbia River Valley, subject to periodic overflow and silting. It has a pH of 4.8.

3. *Klamath peat.*—This soil is a well-decomposed tule-sedge peat formed under semi-arid conditions east of the Cascade Mountains. It is almost black in color, has a slightly basic reaction, pH 7.7, and is well supplied with soluble salts.[4]

## INFLUENCE OF MANGANESE ON MICROBIAL POPULATION

Samples of the above soils, except Klamath peat which was sent in as a sacked bulk sample, were collected in sterile bottles and brought to the laboratory. They were screened with aseptic precautions, samples weighed out and placed in sterile jars, six for each soil type. Two served as checks, two received $MnSO_4$ in solution at the rate of 40 pounds (equivalent to 15 pounds of Mn) per acre, and two received $MnSO_4$ at 100 pounds (equivalent to 36 pounds of Mn) per acre.[5] Sufficient sterile distilled water was added to bring the soil up to 60% of its saturation capacity and the jars placed in the incubator at 28° C.

After 5 days one jar of each treatment was removed from the incubator and sufficient sterile water added to make a 1:5 extract. This was well shaken and plated out in duplicate, using appropriate dilutions. Peptone-glucose-acid agar was used in the lower dilutions for molds and sodium-albuminate agar on the higher dilutions for bacteria and *Actinomyces*. All plates were incubated at 28° C. Molds were counted and differentiated after 4 days, the bacteria and *Actinomyces* after 10 days. The remaining jars were incubated 30 days, then removed and the counting procedure carried out as previously described.

The results are not presented in detail since noteworthy differences were found in only a few instances. Significant changes resulted from manganese sulfate treatment in the following cases: The 40-pound rate of application doubled the number of molds in Willamette silty clay loam soil in 5 days without appreciably altering the differential count; the effect was still evident though less pronounced at 30 days. The effect produced by the 100-pound treatment was similar but less pronounced, and at 30 days had disappeared. Molds were definitely decreased in Newberg loamy sand by the additions, especially after 30 days. Both the 40- and 100-pound treatments

[4]Pot and field trials with some of these soils have indicated that increased crop yields result from the application of manganese to the Klamath peat and Braillier peat.

[5]Calculated on the basis of peat soils at 1,000,000 pounds and mineral soils at 2,000,000 pounds per acre.

practically doubled the bacteria and *Actinomyces* in Chehalis silty clay loam at 5 days; at 30 days the bacteria had increased 20 fold, largely at the expense of *Actinomyces*. In Brallier peat soil manganese additions increased both molds and bacteria without appreciably altering the differential count ratios; the 40-pound rate was the more effective and the influence was most pronounced at 5 days.

## INFLUENCE OF MANGANESE ON SOIL RESPIRATION

Since the foregoing results appeared inconclusive, it was deemed desirable to carry out a more comprehensive experiment on a few soils of widely different manganese content. If manganese exerts an appreciable effect on the microorganisms of the soil, the effect should be directly reflected in assimilative activities as measured by respiration or $CO_2$ evolution. Therefore, a respiration study was carried out with the three following soils: Klamath peat soil, which is low in manganese; Chehalis silty clay loam, which is high in manganese; and Newberg loamy sand, which is intermediate in manganese.

Microbial analyses of the soils at the beginning of respiration were made as described in the previous section, and the results are given in Table 1. The 1:5 water extract was also analyzed for nitrate by the phenoldisulfonic acid colorimetric method of Harper (5), for sulfate by the turbidity method of Schreiner and Failyer (9), and for phosphate by Truog and Meyer's modification of the Deniges method (10). The pH was determined by the Coleman glass electrode. Total nitrogen was determined by the Kjeldahl method and total carbon by dry combustion in an electric furnace. Manganese was determined on the water and ammonium acetate extracts by the method of Willard and Greathouse (11). Results of chemical analyses are shown in Table 2.

Respiration measurements were obtained as described by Bollen (1), using 500 grams of mineral soil and 250 grams of peat soil in quart milk bottles. Eight samples of each soil were placed in the bottles, four serving as checks and four receiving $MnSO_4$ in solution equivalent to 100 pounds per acre. Water to give 60% saturation

TABLE 1.—*Microbial analysis of original soil samples used in respiration experiment.*

| Soil | Moisture, %* | Molds | | | | Bacteria | |
|---|---|---|---|---|---|---|---|
| | | Thousands per gram of soil† | Mucors, % | Aspergilli, % | Penicillia, % | Millions per gram of soil† | Actinomyces, % |
| Klamath peat | 115.0 | 62.5 | 2.4 | 1.6 | 45.6 | 77.0 | 24.7 |
| Chehalis silty clay loam.. | 34.7 | 21.3 | 11.8 | 0.0 | 23.5 | 8.9 | 15.8 |
| Newberg loamy sand | 27.8 | 21.3 | 10.6 | 2.3 | 36.5 | 7.9 | 15.2 |

*60% of saturation capacity.
†Water-free basis.

TABLE 2.—*Chemical analysis of original soil samples.**

| Soil | pH | N as $NO_3$, p.p.m. | S as $SO_4$, p.p.m. | P as $PO_4$, p.p.m. | Total N, % | Total C, % | C:N | Mn, p.p.m.† |
|---|---|---|---|---|---|---|---|---|
| Klamath.. | 7.7 | 65.3 | 43.0 | 1.08 | 1.13 | 11.60 | 10.27 | 15.2 |
| Chehalis.. | 6.8 | 1.0 | 6.1 | 0.46 | 0.21 | 2.14 | 10.25 | 158.3 |
| Newberg.. | 6.4 | 1.9 | 1.0 | 0.42 | 0.07 | 0.85 | 12.92 | 93.2 |

*Data expressed on water-free basis.
†This is the sum of the water-soluble Mn, exchangeable Mn, and easily reducible $MnO_2$, obtained by successive extractions with $H_2O$, neutral normal ammonium acetate, and neutral normal ammonium acetate containing 0.2% hydroquinone.

was added to all soils. Two of each treatment were placed on the pressure line for measurement of $CO_2$ evolution. Duplicates were autoclaved for 3½ hours. After cooling, these were attached to the pressure line with cotton plug protection against contamination.

The $CO_2$ evolved was bubbled through normal NaOH in 50-ml test tubes, which were replaced each day at first, later at longer intervals. The absorbed $CO_2$ was determined by double titration, using thymol-blue and brom-phenol-blue. The aeration was carried on for 55 days. The average $CO_2$ evolved by each soil expressed as mgms of C per kgm of soil is plotted on Fig. 1.

## DISCUSSION

From the results for Klamath peat soil and Newberg loamy sand, it is apparent that manganese stimulates microbial activities with a resulting increase in respiration. The Chehalis silty clay loam soil,

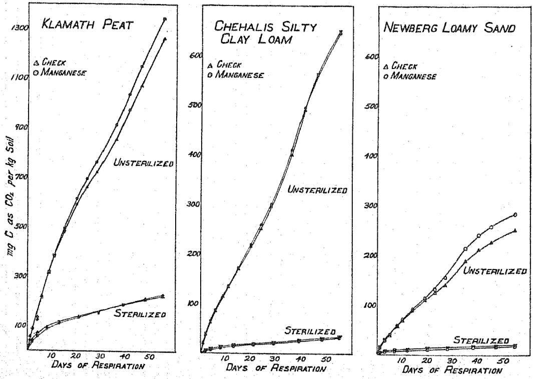


FIG. 1.—The average $CO_2$ evolved by each soil in mgms of C per kgm of soil.

which has the same C:N ratio as the Klamath peat, did not react similarly. It showed no response to added manganese. Analyses of soil extracts show that the average Chehalis profile contains 150 to 200 p.p.m. of extractable magnanese, already optimum or higher.

Response from added manganese sulfate may be due in part to the sulfate supplied, especially for Willamette Valley soils. That the sulfate had little effect on microbial respiration in the soils studied is evident from the respiration curves. The Klamath peat, which gave the greatest response, contains seven times as much sulfate as the Chehalis silty clay loam, which gave no response. In general, the rate of response was inversely proportional to the content of available manganese (Table 2) and bore no relation to the sulfate content.

Manganese gave no increased $CO_2$ production in sterilized samples. Steam sterilization, however, according to Conner (3) and McCool (7), releases large amounts of soluble manganese, and this has been confirmed in our greenhouse work.[6] Beans grown on steam-sterilized soil not only produced greater yields but also had three times the manganese content of beans on unsterilized soil. One hundred pounds of manganese sulfate per acre, therefore, could well have little or no beneficial effect when added to a sterilized soil.

While manganese may affect plant growth (a) directly in nutrition of the plant, (b) indirectly through the soil flora, or (c) in both ways, our experiments do not differentiate these effects. The data presented do show a significant effect of manganese on certain microbial functions in certain soils. Under some conditions this may be the primary influence. In general, however, it would seem that increased plant growth due to manganese additions probably results from direct effects.

## SUMMARY

Manganese sulfate added to several Oregon soils at rates equivalent to 40- and 100-pounds per acre increased by approximately 100% the mold count in Willamette silty clay loam and Braillier peat, and the bacterial count by 160% in the Braillier peat. It produced a 50% decrease in the mold count in Newberg loamy sand.

The microbial production of $CO_2$ was increased by manganese sulfate additions at the rate of 100 pounds per acre in the Klamath peat and Newberg soils, but had no apparent effect in the Chehalis silty clay loam. The response was roughly in inverse proportion to available manganese. No effect on nonmicrobial production of $CO_2$ was apparent.

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# EFFECTS OF SINOX, A SELECTIVE WEED SPRAY, ON LEGUME SEEDLINGS, WEEDS, AND CROP YIELDS[1]

Alvin Schwendiman, James H. Torrie, and G. M. Briggs[2]

THE chemical sodium dinitro-ortho-cresylate, known commercially as Sinox, has been used in the United States since 1938 for the control of broad-leaved annual weeds in small grain and flax fields. While Sinox has been used primarily for the control of wild mustard, *Brassica arvensis*, it has given excellent control of other annual weeds.

When Sinox was first used in Wisconsin, in 1940, it became evident that more information was needed as to its effects upon legume seedlings associated with nurse crops in weed-infested fields. Westgate and Raynor (3)[3] are apparently the only workers who have reported studies of this problem. They found that seedling alfalfa was too tender to be sprayed with safety, but that when the plants were 6 weeks old and 2 to 4 inches tall they would tolerate a 1:80 dilution of Sinox with water at a rate of 160 gallons per acre.

The direct effects of Sinox on various weeds and the indirect effects on crop plants and yields have been studied in detail by several workers (1, 2, 3). Data on factors influencing effectiveness, cost of applications, equipment needed, and details of recommendations for various crops and weeds are given in these references. In general, the recommended dilutions of Sinox with water vary from 1:80 to 1:120 and rates of application from 80 to 120 gallons of solution per acre.

This paper reports the results of experiments conducted during the 3-year period 1940 to 1942. The primary object of these experiments was to determine the tolerance of seedlings of alfalfa, red clover, and biennial white sweet clover to Sinox. The effects on associated weeds and on crop yields were measured, but since other workers (1, 2, 3) have made more detailed studies along these lines, these phases of the work will not be discussed in detail. The methods and results of each year are presented separately because of differences in experimental methods used in different years. In 1940 the experiments were conducted in Sheboygan and Milwaukee counties and in 1941 and 1942 at the University Hill Farms, Madison, Wis. In all three years a 1% solution of Sinox which contained 2 pounds of ammonium sulfate per 100 gallons of solution was used. According to Robbins, Crafts, and Raynor (2, pages 189–192), ammonium sulfate increases the speed and effectiveness of the killing action such that rain falling 30 to 60 minutes after spraying does not nullify the action of the chemical. Spray pressures used and the temperature and humidity at the time of spraying were not recorded as it has been shown by Westgate and Raynor (3, pages 15–17) that pressures between 75 and 150

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[3]Figures in parenthesis refer to "Literature Cited", p. 908.

pounds per square inch are satisfactory and that only at temperatures below 55°F and at low humidities is the rate and effectiveness of action much reduced.

## 1940 EXPERIMENTS

### METHODS

During 1940, four weed-infested grain fields seeded to legumes were sprayed with Sinox in Milwaukee and Sheboygan counties. In each field several strips were sprayed. Adjacent unsprayed strips were used as controls. All applications were made between May 24 and June 8 when the mustard had from 3 to 7 leaves and the grain was 5 to 8 inches tall. The legume seedlings were 1 to 3 inches tall and had from 4 to 6 leaves. The spray rig used on fields 1, 2, and 3 (Table 1) consisted of a 200-gallon tank mounted on a truck equipped with a pump having a delivery capacity of 15 gallons per minute. The spray boom was 22 feet long and was equipped with nozzles delivering fan-shaped sprays. Field 4 was sprayed with a small, portable two-wheeled rig having a 25-gallon tank and a pump capacity of 1¼ gallons per minute. This rig had a single nozzle which delivered a conical-shaped spray covering an area about 6 feet in diameter.

The weed counts and yields were taken on 1/5,000-acre paired quadrats selected at random on treated and untreated areas. Twenty to 30 paired quadrats were taken on all fields. With the exception of field 2 where counts were made, the legume stands were estimated. All data on legumes and weeds were taken just before grain harvest.

### RESULTS

The data in Table 1 give the results obtained during 1940. Sweet clover was very susceptible to the killing action of Sinox. The alfalfa on fields 2 and 3 showed considerable tolerance to Sinox and both of these fields had a good stand of alfalfa on the sprayed areas in the

TABLE 1.—*Effect of 100 gallons of a 1% Sinox solution per acre on legume stands, weeds, and grain yields for four fields in Sheboygan and Milwaukee counties during 1940.*

| Field number and location | Nurse crop and legume | Legume stands | | Weeds and % control* | | | Grain yield, bu. per acre | |
|---|---|---|---|---|---|---|---|---|
| | | Treated | Untreated | WM | WB | LQ | Treated | Untreated |
| Field 1, Sheboygan County | Barley Sweet clover | Trace | Very good | 100 | 98 | — | ——† | ——† |
| Field 2, Sheboygan County | Oats Alfalfa | Good | Very good | 100 | 98 | 98 | 114.0 | 100.5 |
| Field 3, Milwaukee County | Barley Alfalfa | Medium | Good | 98 | 98 | 80 | 57.6 | 42.7 |
| Field 4, Milwaukee County | Barley Alfalfa | Trace | Very good | 100 | 98 | — | 37.0 | 28.5 |

*WM = Wild mustard; WB = Wild buckwheat; LQ = Lambsquarter.
†No yield taken.

spring of 1941. The almost complete killing of alfalfa on field 4 was attributed to the use of the small, portable sprayer equipped with a single nozzle. The amount of spray applied could not be accurately controlled, and the rate of application was apparently much in excess of 100 gallons per acre.

In field 2 there was an average of 20 alfalfa plants per square foot on the untreated areas and an average of 12 per square foot on the treated areas. The number of wild mustard plants per square foot in the untreated areas varied from an average of less than 1 for field 1 to 12 for field 3. The percentage control was estimated for weeds other than wild mustard. Wild buckwheat, *Polygonum convolvulus*, which is a very prevalent and troublesome weed in Wisconsin grain fields, was controlled about 98% in all fields. Lambsquarter, *Chenopodium album*, however, was more resistant in field 3. The yield increase on field 2 was not significant, but on fields 3 and 4 the increases were significant at the 1% level.

## 1941 EXPERIMENTS

### METHODS

During 1941, a trial was conducted at the University Hill Farms at Madison, Wis., to determine the effect of a 1% Sinox solution sprayed at rates of 60, 80, and 100 gallons per acre on the stand of sweet clover, red clover, and alfalfa. The effects of these applications on the control of wild mustard, Indian mustard, *Brassica juncea*, and wild turnip, *B. campestris*, and on the stand and yield of flax were also observed. In order to have the plants at different stages of growth when sprayed, seedings were made at three dates, *viz.*, April 28, May 13, and May 24. The design used was a two-way whole plot with three replicates. The individual plots were 22×24 feet. The legumes were seeded at the rate of 12 to 14 pounds per acre and the flax at 3 pecks per acre. Scarified weed seeds were sown at the rate of 200 per square yard on a single square yard area in the center of each individual plot. The spray applications were made on June 18. A stationary pump was located at the side of the field and an 18-foot boom with hose attachment was pulled across the field.

Counts were made on the stands of legumes, weeds, and flax on June 25 and again on the legumes on September 12. Plant counts and yield data were taken on 1/5,000-acre quadrats located in the center of each plot where the weeds had been sown. All weeds in the treated and untreated areas were removed at the time of counting in order to prevent seed setting. The fall counts on legumes were made on identically the same areas as the spring counts.

### RESULTS

The data in Table 2 describe the height and stage of plant development at the time of spraying. In Table 3 the effects of the Sinox applications are indicated as the percentage reduction of legume, weed, and flax stands expressed as percentages of the unsprayed checks. The smaller plant counts, especially flax, for the May 13 seeding were the result of dry weather following seeding. It should be noted that sweet clover showed its greatest tolerance to Sinox in the May 13 seeding but was very susceptible in the other seedings.

TABLE 2.—*Stages of development of legume, weed, and flax seedlings when sprayed with Sinox on June 18, 1941.*

| Date seeded | Days from seeding to spraying | Height and stage of development | | |
|---|---|---|---|---|
| | | Legumes | Weeds | Flax |
| Apr. 28 | 51 | 5–8 inches | 16–18 inches; full bloom | 14–16 inches; early bloom |
| May 13 | 36 | 4–6 inches | 10–12 inches; early bloom | 10–12 inches |
| May 24 | 25 | 1–3 inches; 5–8 leaves | 2–4 inches; 5–8 leaves | 4–6 inches |

TABLE 3.—*Effects of a 1% solution of Sinox upon the stands of legumes, weeds, and flax when applied at different rates and stages of growth on June 18, 1941.*

| Date of seeding | Gallons of spray per acre | Alfalfa | | Red clover | | Sweet clover | | Wild mustard June 25 | Indian mustard June 25 | Wild turnip June 25 | Flax June 25 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | June 25 | Sept. 12 | June 25 | Sept. 12 | June 25 | Sept. 12 | | | | |
| | | | | | *Plants per Square Foot* | | | | | | |
| Apr. 28 | 0 | 19 | 11 | 13 | 10 | 9 | 3 | 11 | 24 | 16 | 66 |
| May 13 | 0 | 11 | 9 | 18 | 6 | 8 | 6 | 10 | 12 | 16 | 25 |
| May 24 | 0 | 21 | 15 | 33 | 15 | 19 | 11 | 15 | 22 | 20 | 62 |
| | | | | | *Reduction in Stand as Percentage of Check* | | | | | | |
| Apr. 28 | 60 | 4 | 0 | 18 | 0 | 95 | 100 | 0 | 55 | 26 | 5 |
| | 80 | 0 | 0 | 14 | 3 | 100 | 100 | 21 | 32 | 21 | 13 |
| | 100 | 28 | 27 | 15 | 41 | 100 | 100 | 40 | 51 | 50 | 19 |
| May 13 | 60 | 0 | 0 | 0 | 0 | 53 | 58 | 11 | 9 | 14 | 22 |
| | 80 | 0 | 0 | 10 | 0 | 63 | 73 | 15 | 0 | 16 | 24 |
| | 100 | 12 | 0 | 21 | 0 | 91 | 79 | 16 | 27 | 18 | 31 |
| May 24 | 60 | 49 | 33 | 62 | 76 | 75 | 90 | 80 | 81 | 65 | 20 |
| | 80 | 51 | 33 | 66 | 73 | 99 | 100 | 89 | 81 | 81 | 29 |
| | 100 | 53 | 49 | 66 | 67 | 99 | 99 | 95 | 95 | 80 | 24 |

Both alfalfa and red clover had developed a high resistance to Sinox at an age of about 5 weeks (Table 3). This resistance as shown for the May 13 seeding was not appreciably reduced for the April 28 seeding. All the legumes seeded May 24 were most susceptible when sprayed about 3½ weeks later. With the exception of sweet clover, however, the number of plants remaining after spraying still provided a good stand. The September counts for the May 24 seeding show a reduction almost twice as great for red clover as for alfalfa. It is believed that since both the seeding and spraying dates were very late, the lower survival of red clover may be attributed

largely to the fact that recovery from spray injury had to occur during the driest portion of the year and, not being as drouth resistant as alfalfa, it showed an abnormal reduction in stand. The various rates of application appear to have had but little effect on the percentage reduction of the legumes.

The best control of weeds was obtained when the spray was applied at an early stage of plant growth. At this time the injury to the legume seedings was also the greatest. It is evident that delaying the time of spraying to 5 or 6 weeks after seeding to allow for the development of resistance to Sinox by the legumes results in very poor weed control. The higher percentage control of weeds for the April 28 seeding as compared with the May 13 seeding is attributed to the more dense stand of flax for the former date. This indicates that weeds are more susceptible to Sinox when the stand of competing plants is good and the weeds more tender.

No information was secured as to how the reduced weed stands might have increased yields, since all weeds were removed shortly after the spray application. However, a measure of the reduction in yield caused by the spray and by the weeds up to the time they were sprayed or removed by hand was secured by taking yields on the sprayed and unsprayed plots each with and without weeds. The yield of flax for the April 28 seeding was reduced approximately 40% by the spray treatment and an additional 40% from weed competition. The flax of this date of seeding was in early bloom when sprayed and was severely burned by the spray. The reduction in yield caused by the weeds in the May 13 seeding up to the time they were removed was about 60% and for the May 24 seeding 15 to 20%. On the areas which had no weeds the average yield reductions for the three rates of Sinox application were 11% for the May 13 seeding and 7% for the May 24 seeding. These figures emphasize the fact that when Sinox is applied at a late stage of growth, flax is severely injured and weed control is poor.

## 1942 EXPERIMENTS

### METHODS

The 1942 experiments were conducted at the University Hill Farms, Madison, Wis., to determine the effect of a 1% Sinox solution sprayed at rates of 60, 80, and 100 gallons per acre on the stands of sweet clover, red clover and alfalfa, on the control of wild mustard and lambsquarter, and on the yield of flax. A split-plot design with four replicates was used. The size of each plot was 3×8 feet. The flax was seeded at 3 pecks per acre over the entire area, and the legumes were seeded at rates of 12 to 14 pounds per acre in randomized strips within each block. Seed of each of the weeds was broadcasted over the entire area at a rate of approximately 10 pounds per acre. All seedings were made on April 22. The spray was applied June 2 and June 9. Small hand sprayers were used which delivered a continuous spray from graduated glass jars. The position of spray treatments was determined at random within each legume strip in each block. The flax was harvested and weed counts made on August 3, 1942. The stand of legumes was determined on September 15 by counting the number of plants found in three square-foot areas taken at random in each plot.

## RESULTS

The data in Table 4 give the stages of plant development at each of the two dates of spraying, while those in Table 5 show the effects of the sprayings on the stand of the legumes and weeds and on the yield of flax. It is again evident that sweet clover is very susceptible to Sinox, while red clover and alfalfa show considerable tolerance at rates which give excellent weed control.

TABLE 4.—*Stages of development of legumes, weeds, and flax seeded on April 22 and sprayed at two dates.*

| Plant | Sprayed June 2 | | Sprayed June 9 | |
|---|---|---|---|---|
| | Height, inches | No. true leaves | Height, inches | No. true leaves |
| Alfalfa | 2–4 | 3–5 | 4–6 | 5–8 |
| Red clover | 2–3 | 2–3 | 3–5 | 4–5 |
| Sweet clover | 2–3 | 3–5 | 3–5 | 4–6 |
| Wild mustard | 4–6 | 4–6 | 10–18 | Early bloom |
| Lambsquarter | 2–3 | 3–6 | 4–8 | 8–12 |
| Flax | 6–10 | — | 10–16 | — |

TABLE 5.—*Effects of Sinox spray upon the stands of legumes and weeds and upon the yields of flax when applied at three rates and two dates.*

| Plant (seeded April 22) | Unsprayed check, No. of plants per sq. ft. | Sprayed June 2, 1942* | | | Sprayed June 9, 1942* | | |
|---|---|---|---|---|---|---|---|
| | | 60 gals. | 80 gals. | 100 gals. | 60 gals. | 80 gals. | 100 gals. |
| | | Reduction of Stand in Percentage of Check | | | | | |
| Alfalfa | 54 | 38 | 54 | 54 | 12 | 34 | 22 |
| Red clover | 38 | 7 | 14 | 0 | 7 | 7 | 0 |
| Sweet clover | 10 | 95 | 97 | 100 | 91 | 100 | 97 |
| Wild mustard | 3.2 | 96 | 97 | 99 | 62 | 81 | 66 |
| Lambsquarter | 1.8 | 81 | 93 | 95 | 21 | 49 | 33 |
| | | Yields in Bushels per Acre† | | | | | |
| Flax | 8.6 | 16.9 | 15.7 | 15.2 | 15.6 | 16.3 | 15.2 |

*1% Sinox at the rate per acre indicated.
†Difference required for significance at the 5% level, 2.4 bushels.

While the tolerance of alfalfa to Sinox increased between June 2 and June 9, it is evident that the poorer weed control would not justify the delay in application. Flax yields were doubled for almost all rates and dates of application. The poorer weed control at the second date of application was not reflected in the flax yields. Apparently this was because the weeds which were not killed were injured so severely that they offered little competition to the flax.

## DISCUSSION

An explanation of the relative tolerance of sweet clover, alfalfa, and red clover to Sinox is found in their morphological and develop-

mental characteristics. Examination of spray-injured sweet clover seedlings has shown that nearly all axillary buds fail to develop when most or all of the leaves are killed. This is especially true in very young seedlings or in older plants which are shaded to a considerable extent by the nurse crop or weeds. Sweet clover plants when 5 to 6 weeks old and grown with very little competition, as for the May 13 seeding in Table 3, showed considerable recovery from axillary buds. Buds and leaf primordia of red clover have better protection than those of either alfalfa or sweet clover. This is because red clover has large stipules and practically no internodal elongation in the early developmental stages. Many spray-injured red clover plants with all leaves destroyed and appearing to be entirely dead were observed to send out new leaves within 6 to 8 days after spraying. The basal internodes of alfalfa elongate less than those of sweet clover. This provides alfalfa with more basal axillary buds near the ground than sweet clover. Likewise, alfalfa produces basal adventitious buds while sweet clover does not. The rather fleshy leaves of sweet clover showed signs of injury more rapidly than did the leaves of alfalfa and red clover. This would indicate either a more rapid penetration of the spray into the sweet clover tissue or a greater sensitivity.

The data in Tables 3 and 5 show that in 1941 alfalfa was more tolerant to Sinox than red clover, but that the reverse was true for 1942. A possible explanation of this observation is that in both years the legume with the best stand before treatment showed the greatest percentage reduction from the spray treatment. This indicates a higher percentage survival of the legumes in sparse stands and a lower survival in dense stands.

During 1943 one field seeded to red clover with a very heavy stand of barley was sprayed when the barley was 1 foot high. Observations 1 week after spraying showed normal recovery of the red clover. Extremely dry weather followed, however, and practically 100% of the clover died. Adjacent fields with a less dense nurse crop showed good recovery.

Based upon the actual number of alfalfa plants surviving on the sprayed areas in September of 1941 and 1942, it would seem safe to recommend the use of Sinox on alfalfa seedings infested with weeds. This is in agreement with the results obtained in the 1940 experiments with the exception of one field and with observations made on several commercially sprayed fields in various parts of Wisconsin. The 1942 experimental results and field observations indicate that red clover may be sprayed with as great a degree of safety as alfalfa. There are at least two possible reasons why legumes sprayed at an early stage of growth are more susceptible to injury from Sinox when planted late in the season than when planted early. First, the higher temperatures of late spring and early summer result in the development of more succulent and spray-susceptible seedlings, and second, the moisture and temperature conditions are less favorable for the recovery of the spray-injured plants. The greater susceptibility of weeds to Sinox would make these considerations relatively less important in determining their resistance to this material.

## SUMMARY AND CONCLUSIONS

Weed-infested fields and experimental plots seeded to alfalfa, red clover, and sweet clover with nurse crops were sprayed with a 1% solution of Sinox. The rates of application were 60, 80, and 100 gallons per acre applied at several stages of plant growth. The results and conclusions of the experiments conducted in 1940, 1941, and 1942 are summarized as follows:

1. Biennial white sweet clover seedlings were very susceptible to injury by Sinox at all rates of application and showed 60 to 100% reduction in stand when sprayed at all stages of growth.

2. Alfalfa and red clover seedlings were markedly more tolerant to Sinox in all growth stages than were sweet clover seedlings. Alfalfa and red clover developed a high resistance at an age of about 5 to 6 weeks. Up to 4 weeks of age the reduction in stand varied from 0 to 70%. However, a high percentage reduction occurred only where the stand was very dense. In practically all cases where alfalfa and red clover were sprayed a satisfactory stand of these legumes was secured. Extremely dry weather following spraying, however, may result in the failure of legumes to recover satisfactorily.

3. Attempts to reduce the injury to the legume seedlings by delaying the date and reducing the rate of application proved unsatisfactory as this resulted in greater injury to the nurse crop and poorer weed control.

4. The volume of spray applied within the range of 60 to 100 gallons per acre did not appear to be of much importance in determining injury to the legume seedlings.

5. Wild mustard, wild buckwheat, lambsquarter, and other broad-leaved annual weeds were controlled 80 to 100% by spray applications of 80 to 100 gallons per acre of a 1% Sinox solution at a time when the weeds had from three to seven leaves. Less effective control resulted when less than 80 gallons per acre was used or when the weeds were sprayed in more advanced stages of growth.

6. The yields of oats, barley, and flax were increased 10 to 100% by spraying, depending upon the seriousness of the weed infestations and the effectiveness of weed control. Delayed spraying resulted in poor weed control and injury to the grain crop.

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# NOTES

## EFFECT OF SODIUM ACETATE ON PLANT GROWTH AND SOIL pH VALUE AS INDICATED BY GREENHOUSE EXPERIMENTS

A FERTILIZER material containing sodium acetate as an impurity is being produced as a byproduct of the manufacture of certain war chemicals. In a study of the suitability of this byproduct for agronomic use, experiments were carried out to determine the effect of sodium acetate on the growth of German millet under greenhouse conditions. As a search of the literature revealed no information on the plant-growth effects of sodium acetate, it would seem of interest to record the results of these experiments.

The experiments were made in quadruplicate in 8-inch, bottom-pierced, clay pots, each of which contained 11 pounds of Evesboro loamy sand soil from the Beltsville Research Center, Beltsville, Md. All the pots received a basal application of 0–16–8 fertilizer at the rate of 2,000 pounds per acre (2,000,000 pounds of soil). One series received no nitrogen fertilizer, while the other received nitrogen at the rate of 100 pounds per acre derived equally from ammonium sulfate and sodium nitrate. Crystallized sodium acetate containing 3 molecules of water was applied at rates of 52.5 to 840 pounds per acre. The fertilizer and the sodium acetate were thoroughly mixed with the upper half of the soil in each pot, although the rates of application were based on the total weight of soil in the pot. The millet was planted on July 3, 1942, and the seedlings were thinned to seven uniformly spaced plants when they were 2 to 4 inches high. The moisture content of the soil was maintained at a uniform level by daily applications of tap water. The plants (aerial portions) were harvested on August 28, dried in a forced-draft oven at 150° F for 48 hours, and exposed to the laboratory atmosphere for several days before they were weighed.

As shown in Fig. 1, applications of sodium acetate at rates up to 840 pounds per acre had little or no effect on the dry-weight yields of

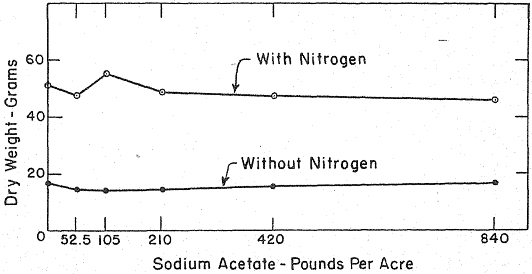


FIG. 1.—Effect of sodium acetate on growth of German millet.

millet in either the presence or the absence of nitrogen fertilizers. Also, the acetate-treated plants did not differ greatly from the controls in their development and appearance.

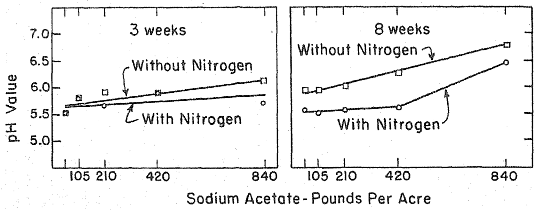


FIG. 2.—Effect of sodium acetate on soil pH value.

By means of the glass electrode, the pH values of 1:1 aqueous suspensions of 10-gram samples of soil from the center upper portion of each pot were determined at 3 and 8 weeks, respectively. In the absence of nitrogen fertilizer, the effect of the sodium acetate was to increase the pH value of the soil, usually in proportion to the quantity of sodium acetate applied (Fig. 2). The effect was much more pronounced at 8 weeks than at 3 weeks, probably owing to the greater decomposition of the acetate ion during the longer period of its contact with the soil. In the presence of nitrogen fertilizer, the pH value of the soil during the first 3 weeks tended to increase slightly with increase in the quantity of sodium acetate applied; at 8 weeks, however, the pH values of all the cultures, except those with 840 pounds of sodium acetate, were nearly identical and were generally somewhat lower than those of the same culture at 3 weeks. It appears that with the longer period of incubation the soil acidifying effect of the ammonium sulfate was approximately counterbalanced by the total alkalizing effect of the sodium nitrate and the sodium acetate at levels up to 420 pounds of the latter.—EILIF V. MILLER AND K. D. JACOB, *Division of Soil and Fertilizer Investigations, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture, Beltsville, Md.*

## GREENHOUSE SEED TREATMENT STUDIES ON HEMP

HEMP was designated by the U. S. Dept. of Agriculture as a "War Crop" for 1943 and a program production goal of 300,000 acres was planned. The annual average production of hemp in the United States for fiber use in twines and cordage for the period 1929 to 1938 was less than 2,000 acres. In order to plant the large acreage desired in 1943, the Department of Agriculture contracted in 1942 with Kentucky farmers for 37,000 acres of hemp solely for seed production. The seed yields in 1942 were not as large as anticipated being only sufficient for planting approximately 185,000 acres for fiber

production. The germination of some lots of seed was low due to immature harvesting and adverse weather conditions which prevented early threshing. In order to utilize the seed as advantageously as possible for fiber production in 1943, questions arose regarding the value of seed treatment. There is little recorded evidence to indicate that hemp has been troubled by seedling diseases and seed treatments have not been recommended in the past for this crop. The Bureau of Plant Industry, Soils, and Agricultural Engineering was requested to determine benefits, if any, of seed treatment for hemp.

Results are presented in Table 1 reporting greenhouse tests arranged with the following cooperators: Dr. Benjamin Koehler, Agricultural Experiment Station, Urbana, Ill.; Howard V. Jordan, U. S. Dept. of Agriculture and Agricultural Experiment Station, Madison, Wis.; Dr. Richard Weindling, U. S. Dept. of Agriculture and Agricultural Experiment Station, Clemson, S. C.; Dr. J. A. Pinckard, Agricultural Experiment Station, State College, Miss.; and R. W. Leukel, U. S. Dept. of Agriculture Plant Industry Station, Beltsville, Md. Data obtained by other experiment stations cooperating in the tests seemed to be in line with those presented here.

The seed lots used were Kentucky-produced seed of high, medium, and low germination. The lots of seed tested in Wisconsin, Mississippi, and South Carolina were identical, and the Maryland and Illinois experiments had other lots that were identical. The greenhouse temperatures were similar for all locations, ranging from approximately 65° to 70°F. The choice of dusts for the experiments was the selection of the individual cooperators. The data in Table 1 are an average of three replications in Wisconsin, Mississippi, and South Carolina; four replications in Illinois; and five replications in Maryland. The treatments were randomized in Wisconsin, Mississippi, and South Carolina, but systematically arranged in Maryland and Illinois. Recorded results are on the number of seedling plants that emerged per 100 seeds planted. Despite systematic arrangement at two locations, analyses of variance were made throughout in order to obtain approximate differences required for significance.

In general, it appears that emergence from seed treated with any of the dusts at recommended rates may be expected to be better than that obtained from untreated seed. Evidence of Ceresan damage was obtained in the Wisconsin studies, but with an equal or heavier application at Beltsville, Md., no evidence of such damage was indicated.

Hemp seed for sowing has been sold to farmers at prices ranging from \$5.00, to above \$10.00 per bushel of 44 pounds. For fiber production the recommended rate of sowing is 55 pounds of seed per acre. Seed treatment of seed as valuable as hemp seed may well be worthwhile. In the production of hemp a contracting hemp processing mill usually distributes all seed to contract growers. This system of production makes it easily possible for the hemp mills to arrange for uniform seed treatment expertly supervised at centralized locations and at minimum expense due to the large bulk handled. It saves the grower the trouble of doing the job at a season when his time is needed for other jobs.

TABLE 1.—*A summary of data from greenhouse studies on hemp seed treatments.*

| Treatment | Rate of application, ounces per bushel | | | | | | Emergence, % | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wis. | Miss. | S. C. | Md.* | Md.* | Ill. | Wis. | Miss. | S. C. | Md.* | Md.* | Ill. |
| | Seed Lot No. 1763 | | | Seed Lot No. 6219 | | | | | | | | |
| No treatment | — | — | — | — | — | — | 63.7 | 36.3 | 66.3 | 61.8 | 63.6 | 65.5 |
| Ceresan 2% | — | 3.5 | 3.5 | — | — | — | — | 44.3 | 74.3 | — | — | — |
| N. I. Ceresan 5% | 2.8 | — | 3.5 | 5.0 | 0.5 | 0.5 | 52.0 | — | 69.3 | 87.0 | 84.4 | 84.8 |
| N. I. Semesan Jr. 1% | 0.8 | — | — | — | — | — | 73.3 | — | — | — | — | — |
| Spergon | 11.3 | 21.8 | 7.0 | 20.0 | 2.0 | 1.5 | 80.7 | 46.0 | 72.3 | 81.8 | 73.2 | 83.5 |
| Cuprocide | 9.7 | 22.5 | 7.0 | — | — | — | 78.7 | 48.3 | 72.7 | — | — | — |
| Copper carbonate | — | — | — | 20.0 | 2.0 | — | — | — | — | 76.8 | 71.6 | — |
| Zinc oxide | — | 24.6 | 14.1 | — | — | — | — | 49.7 | 70.3 | — | — | — |
| Arasan | 1.2 | 4.2 | — | 20.0 | 2.0 | 1.0 | 79.0 | 40.7 | — | 74.2 | 75.2 | 82.3 |
| Fermate | — | — | — | — | — | 1.5 | — | — | — | — | — | 86.8 |
| Barbak D | — | — | — | — | — | 1.5 | — | — | — | — | — | 82.5 |
| | Seed Lot No. 2142 | | | Seed Lot No. 6190 | | | | | | | | |
| No treatment | — | — | — | — | — | — | 53.7 | 38.3 | 55.7 | 45.6 | 44.8 | 47.8 |
| Ceresan 2% | — | 3.5 | 3.5 | — | — | — | — | 38.7 | 63.3 | — | — | — |
| N. I. Ceresan 5% | 2.8 | — | 3.5 | 5.0 | 0.5 | 0.5 | 45.3 | — | 53.3 | 56.4 | 57.2 | 57.3 |
| N. I. Semesan Jr. 1% | 0.8 | — | — | — | — | — | 53.7 | — | — | — | — | — |
| Spergon | 11.3 | 21.8 | 7.0 | 20.0 | 2.0 | 1.5 | 58.0 | 37.7 | 59.7 | 53.6 | 51.8 | 58.8 |
| Cuprocide | 9.7 | 22.5 | 7.0 | — | — | — | 58.7 | 46.0 | 66.3 | — | — | — |
| Copper carbonate | — | — | — | 20.0 | 2.0 | — | — | — | — | 46.4 | 50.8 | — |
| Zinc oxide | — | 24.6 | 14.1 | — | — | — | — | 40.7 | 64.0 | — | — | — |
| Arasan | 1.2 | 4.2 | — | 20.0 | 2.0 | 1.0 | 53.3 | 33.0 | — | 53.2 | 56.4 | 52.3 |
| Fermate | — | — | — | — | — | 1.5 | — | — | — | — | — | 61.0 |
| Barbak D | — | — | — | — | — | 1.5 | — | — | — | — | — | 55.0 |

| | Seed Lot No. 3136-½ | | | Seed Lot No. 6215 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No treatment | — | — | — | — | — | — | 24.0 | 19.0 | 24.0 | 19.8 | 20.6 | 13.5 |
| Ceresan 2% | — | 3.5 | 3.5 | — | — | — | — | 10.7 | 31.0 | — | — | — |
| N. I. Ceresan 5% | 2.8 | — | 3.5 | 5.0 | 0.5 | 0.5 | 16.3 | — | 31.0 | 18.6 | 17.4 | 24.5 |
| N. I. Semesan Jr. 1% | 0.8 | — | — | — | — | — | 35.0 | — | — | — | — | — |
| Spergon | 11.3 | 21.8 | 7.0 | 20.0 | 2.0 | 1.5 | 30.3 | 15.0 | 30.0 | 22.2 | 18.0 | 23.3 |
| Cuprocide | 9.7 | 22.5 | 7.0 | — | — | — | 27.3 | 29.3 | 29.3 | — | — | — |
| Copper carbonate | — | — | — | 20.0 | 2.0 | — | — | — | — | 21.4 | 26.0 | — |
| Zinc oxide | — | 24.6 | 14.1 | — | — | — | — | 20.3 | 31.3 | — | — | — |
| Arasan | 1.2 | 4.2 | — | 20.0 | 2.0 | 1.0 | 28.3 | 11.7 | — | 18.4 | 17.2 | 23.0 |
| Fermate | — | — | — | — | — | 1.5 | — | — | — | — | — | 25.8 |
| Barbak D | — | — | — | — | — | 1.5 | — | — | — | — | — | 22.3 |
| Difference required for significance between treatments: Odds 99.1 | | | | | | | 18.0 | 20.6 | 14.6 | 8.5 | 8.5 | 8.9 |
| Difference required for significance between treatments: Odds 19.1 | | | | | | | 13.3 | 15.3 | 10.9 | 6.3 | 6.4 | 6.7 |

*U. S. Dept. of Agriculture, Bureau of Plant Industry, Soils, and Agricultural Engineering, Beltsville, Md., two rates of application.

Variations in stands of plants of hemp do not necessarily indicate corresponding differences in total tonnage of hemp stalks per acre of ground. Experiments reported by Herzog,[1] together with unpublished data collected by the U. S. Dept. of Agriculture, have shown that sowings of 3, 4, and 5 pecks per acre resulted in no significant differences in yields of stalks. However, the thicker rates of seeding produced more plants and plants with smaller diameter stalks and higher fiber content. It is well recognized that the percentage of fiber in relation to wood in thin stems is greater than in thick stems. The increase of fiber under normal conditions between sowings of 3 to 5 pecks of seed per acre may amount to approximately 50 to 100 pounds more fiber per acre. This increased return makes it evident that seed treatment in addition to providing a saving in outlay for expensive seed may insure more productive yields of fiber per area of ground.—BRITTAIN B. ROBINSON, *Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, Washington, D. C.*

[1]HERZOG, R. O. Hanf und Hartfasern. Technologie der Textilfasern V. Band, 2 Teil. 1927.

## A METHOD FOR INOCULATING SMALL LOTS OF LEGUME SEED[1]

WHEN seed treatment studies involving several leguminous plants were begun at the Alabama Agricultural Experiment Station in 1940, certain results were obtained that suggested a time-saving method for the inoculation of numerous small lots of seed. The method proved so effective that it is now being used in the legume breeding nurseries at Auburn whenever inoculation of the seed is deemed advisable. It is also possible, by this method, to use legume inoculants in combination with seed disinfectants ordinarily considered to be lethal to root nodule organisms.

The method developed dispenses with the ordinary direct application of the inoculent to the seed. Rather, it is an indirect method involving the incorporation of commercial legume culture into finely-ground stable manure and application to the plot rather than to the seed.

A small-sized package of culture (for 100 to 120 pounds of seed) was thoroughly mixed into 300 pounds of well-composted, finely ground stable manure. The mixture was usually sacked and allowed to stand for 1 or 2 days, but it has been used effectively immediately after mixing or as long as 1 week after mixing. In the case of row crops, the inoculated manure was evenly applied to open furrows at the rate of 300 pounds per acre. The seed was dropped into the row directly in contact with the inoculated manure and covered. Small seed, such as crimson clover, was mixed into the inoculated manure and broadcast onto the plot prior to raking in or cultipacking. The crimson clover yields reported in Table 1 were obtained from plots sowed with seed treated in this manner.

[1]Contribution from the Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn, Ala. This work was supported in part by a grant from The Nitragin Co., Inc., Milwaukee, Wis.

The indirect method of inoculation was proved to be effective on two summer legumes, peanuts and soybeans, and on three winter legumes, blue lupines, monantha vetch, and crimson clover.

The use of manure at such a low rate did not contribute to any apparent variability in growth within or between plots of the same treatment. In the instance of soybeans, the stand of soybeans was reduced when the seed was sowed in contact with manure, but injury of this nature was not evident in the case of the other crops included in the tests. The use of manure (uninoculated) appeared to have stimulated the yield of hay and nuts of Spanish peanuts, but the low incidence of nodules on the plants treated in this manner indicates this was not due to the occurrence of legume bacteria of the cowpea group in the manure used. Actually, the plants, like all those growing on the uninoculated plots, showed evidences of inoculation deficiencies as they approached maturity.

To test the effectiveness of the indirect method of inoculation further, seed treated with Ceresan was planted in contact with

TABLE 1.—*Yields of certain leguminous plants as affected by direct and indirect application of legume bacteria, Auburn, Alabama, 1942.**

| Treatment | Yield, lbs. per acre† | | No. nodules per 12 plant sample‡ |
|---|---|---|---|
| | Hay | Nuts | |
| **Peanuts** | | | |
| None | 2,800 | 1,260 | 13.25 |
| Inoculated | 2,979 | 1,517 | 239.25 |
| Manure | 2,866 | 1,419 | 8.50 |
| Inoculated manure | 3,174 | 1,551 | 173.50 |
| Ceresan 2% | 3,230 | 1,456 | 8.25 |
| Inoculated manure plus Ceresan 2% | 3,300 | 1,834 | 212.25 |
| **Soybeans** | | | |
| None | 2,760 | — | — |
| Inoculated | 2,840 | — | — |
| Inoculated manure | 2,880 | — | — |
| Manure | 2,240 | — | — |
| Ceresan 2% | 3,060 | — | — |
| Inoculated manure plus Ceresan 2% | 3,220 | — | — |
| **Blue Lupine§** | | | |
| None | 375 | — | — |
| Inoculated | 963 | — | — |
| Ceresan 2% | 338 | — | — |
| Inoculated manure plus Ceresan 2% | 1,238 | — | — |
| **Crimson Clover**** | | | |
| None | 7,147 | — | — |
| Inoculated manure | 17,016 | — | — |
| Inoculated | 16,335 | — | — |

*0–14–10 applied to all crops at rate of 300 lbs. per acre.
†Average of four 1/220-acre harvests.
‡Average of four 12-plant samples; nodules counted on 9-week-old seedlings.
§Yields given are green weights; low yields are a consequence of severe winter injury.
**Yields given are green weights; average of four 1/5445 acre cuttings.

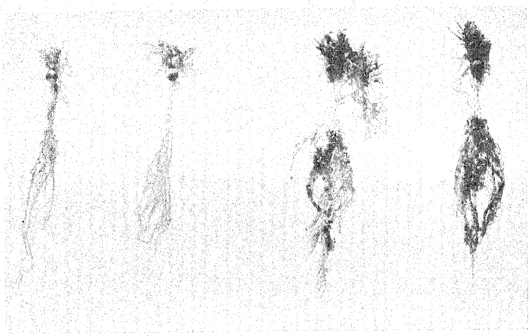

FIG. 1.—Monantha vetch plants dug 5 months after planting. Left, uninoculated; right, planted in contact with inoculated manure. Seed treated with Ceresan in both cases.

inoculated manure. Nodulation was readily accomplished despite the use of this mercury compound, and, from the standpoint of

FIG. 2.—Blue lupine plants dug 5 months after planting. Left, uninoculated; right, planted in contact with inoculated manure. Seed treated with Ceresan in both cases.

yields obtained, the treatment proved to be the most effective of all employed (Table 1, Figs. 1 and 2).

The yields of plots planted with seed inoculated by the indirect method were equal to those planted with seed inoculated in the usual manner in the case of soybeans and crimson clover. In the case of peanuts, the yields of plots planted with seed inoculated by the indirect method were, by statistical analysis, significantly greater than those of plots planted with seed to which the inoculation was applied directly. Although no direct comparison between the two methods was made with blue lupines, the yields of plots planted with seed inoculated by the indirect method and treated with Ceresan were significantly greater than those planted with uninoculated or directly-inoculated seed.—H. R. ALBRECHT, *Alabama Agricultural Experiment Station, Auburn, Alabama.*

# AGRONOMIC AFFAIRS

## PRESIDENT KEIM ISSUES STATEMENT ON THE ANNUAL MEETING

THE annual meeting of the American Society of Agronomy will be held November 10 to 12, 1943, in Cincinnati, Ohio.

In 1917, W. M. Jardine in the December number of the JOURNAL (Volume 9) made the following statement: "Upon our entry into the war, the government had need of the immediate services of every industry, every organization, and every individual, and the response came promptly and loyally from every quarter. Agronomists at once evinced an all-pervading desire to bring to the immediate assistance of the country every ounce of their strength which might be put to practical use. They frequently proved to be the logical men to form "ways and means" committees for devising plans whereby the maximum production could be secured from every man, every horse, every machine, and every acre of ground, quickly, and at the same time jeopardize in no way the permanence of agriculture. Campaigns for increased crop acreages were initiated and carried to successful completion. Seed stocks were inventoried and made available for those in need. Information on every conceivable point relating to agriculture was given to the public through correspondence, public addresses, and the press. This successful participation of agronomists in emergency work is a splendid tribute to their usefulness. It will be continued with increasing vigor."

The agronomists of 1943 have the same responsibility. It is for like reasons that the Executive Committee of the Society feels that the 1943 annual meeting of the Society should be held. Our annual meeting is not a convention, but it is a gathering of scientific workers who probably contribute as much to the food effort of the world as any other organization. The agronomists in every state and in the U. S. Dept. of Agriculture have the responsibility of promoting food production to the maximum. It is the opinion of the officers of the Society that the best interests of the food effort will be served

by holding a meeting, where the knowledge of one becomes the common knowledge of all.

Might I urge each state and the U. S. Dept. of Agriculture to make every possible effort to be well represented at the annual meeting which convenes in Cincinnati on November 10, 1943. The more whole-hearted support given by the membership, the greater will be the benefits derived.

The program committees have arranged excellent programs. The speakers for the general program on Thursday morning will be Dr. L. A. Maynard of the School of Nutrition, Cornell University, who will speak on "The Soil and Crop Basis of Better Nutrition" and Dr. O. E. May, chief of the processing laboratories, U. S. Dept. of Agriculture, who will summarize some of the more important phases of research conducted in these laboratories which relates to the present and future war effort.—F. D. KEIM, *President of the American Society of Agronomy.*

## NEWS ITEMS

ROBERT L. CUSHING, formerly of the Agronomy Department of the University of Nebraska, has been appointed Assistant Professor of Plant Breeding at Cornell University. Recently Professor Cushing was also associated with the Bureau of Plant Industry, U. S. Dept. of Agriculture, and had charge of the grain sorghum investigations for the Nebraska region.

—A—

THE FOLLOWING changes in personnel are reported from the Florida Agricultural Experiment Station at Gainesville:

DOCTOR GORDON B. KILLINGER, formerly Associate Agronomist has been named Agronomist in place of Doctor W. A. Leukel, who died April 27. DOCTOR H. C. HARRIS was named Associate Agronomist, effective September 15. DOCTOR ROGER W. BLEDSOE was named Associate Agronomist, effective September 1. G. T. SIMMS has been appointed Associate Chemist in the Soils Department. DOCTOR ERNEST L. SPENCER has been appointed Soils Chemist at the Vegetable Crops Laboratory at Bradenton. RAYMOND C. BOND has been appointed Assistant Agronomist at the North Florida Experiment Station at Quincy.

—A—

ACCORDING TO *Science*, Doctor E. B. Fred was recently appointed Dean of the College of Agriculture of the University of Wisconsin. Doctor Fred has been Dean of the Graduate School at the University for the past nine years.

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# METHODS OF DETASSELING AND YIELD OF HYBRID SEED CORN[1]

Carl Borgeson[2]

FROM observation, methods of detasseling vary from the seed grower who goes over his crossing plot many times removing only the most advanced tassels each trip, to the producer who waits as long as is safe before beginning detasseling and then attempts to detassel as many plants as possible the first time over the field. The removal of tassels that have not entirely emerged from the leaf sheath is practically impossible without removing at the same time one or two of the upper leaves. Hybrid seed corn producers have asked whether the removal of leaves with the tassel had an effect on seed yields.

Dungan and Woodworth[3] found that the removal of one, two, three, and four leaves with the tassel reduced the yield of grain 8.3, 15.3, 18.1, and 29.2%, respectively. They reviewed previous studies of the effect of detasseling on yield in corn.

The experiment reported here was started in 1940 to determine what effect the removal of different numbers of leaves had on seed yield and whether differences existed among female parents of different hybrids.

## MATERIALS AND METHODS

In 1940, seed stocks of a number of new Minhybrid double crosses were released to Minnesota producers. Six of these double crosses had as a common male parent the single cross A7×A12. This fact enabled seed producers to produce seed of Minhybrids 700 and 701, maturity rating 88 to 92 days; Minhybrids 600 and 601, maturity rating 95 to 101 days; and Minhybrids 500 and 501, maturity rating 103 to 109 days, in one isolated plot. Since the female parents of these varieties varied considerably in maturity and plant habit, particularly width of leaf and type of tassel, this material seemed admirably suited for a study of the effect of leaf removal within and between varieties.

A well-isolated plot of ground that had been in pasture for a number of years was selected for the experiment. Three blocks of four rows each of each female

[1]Contribution from the Division of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minn. Paper No. 2090 of the Journal Series, Minnesota Agricultural Experiment Station. Received for publication May 29, 1943.

[2]Assistant Professor in Agronomy.

[3]Dungan, G. H., and Woodworth, C. M. Loss resulting from pulling leaves with the tassels in detasseling corn. Jour. Amer. Soc. Agron., 31:872–875. 1939.

parent were planted with two male rows between the blocks as a pollinator. This made a total of 12 rows of each female with 40 hills in each row. The male and female parents were planted at the same time, with the exception of Minhybrids 500 and 501 where the female parents were planted several days before the male parent. Five kernels were planted per hill and the hills thinned to three stalks.

Four methods of detasseling were used in the studies, as follows: (1) No leaves removed with the tassel; (2) one leaf removed with the tassel; (3) two leaves removed with the tassel; and (4) three leaves removed with the tassel. The methods of detasseling were randomized within each female parent, but the female parents were planted in a systematic order in the field.

In harvesting, only full stand hills surrounded by corn were selected and the yields per acre determined for these on a 14% moisture basis. The experiment began in 1940 and was repeated on the same field in 1941 and 1942. The data were analyzed statistically by the analysis of variance method.

## RESULTS

The 3-year results, giving bushels per acre for each hybrid and method of treatment as well as least significant differences in bushels, are given in Table 1.

It is apparent from the data in Table 1 that the removal of one leaf did not have a very harmful effect on yield, that when two leaves were removed the yield was significantly lower than when no leaves were removed for each year of the study, and that the removal of three leaves gave, on the average, a reduction in yield of 9.2 bushels per acre in comparison with the removal of no leaves.

To determine whether all hybrids reacted in the same manner to the removal of leaves in detasseling the average yields were calculated for the 3-year period for the four treatments. The data given in Table 2 are percentages of the yield of each hybrid when no leaves were removed. The least significant difference of percentages at the 5% point is expressed in percentage of the average yield when no leaves were removed.

The data in Table 2 show that the removal of one leaf with the tassel caused the greatest reduction in yield for the female parent of Minhybrid 601, although the difference of 6.5% was not significant statistically. The pulling of one leaf with the tassel for the other five hybrids gave only small differences in comparison with the removal of no leaves and two hybrids yielded slightly more when one leaf was removed than when no leaves were removed with the tassel. When two leaves were removed, the four early hybrids, 700, 701, 600, and 601, were reduced in yield from 6.8 to 13.9%. The Minhybrid 701 female parent gave a significant reduction in yield when two leaves were removed as compared with the removal of one leaf. The later maturing broad-leaved parents of 500 and 501 were only slightly reduced in yield by removing two leaves. When three leaves were removed, the two last-named varieties gave the decided reductions in yield in comparison with the removal of no leaves of 10.1 and 12.7%, respectively. The four earlier maturing parents were reduced in yield from 16.6 to 26.8% by the removal of three leaves when compared with the removal of no leaves in detasseling.

TABLE 1.—*Yield in bushels per acre from six corn hybrids for each of three years in relation to the number of leaves removed with the tassel.**

| Hybrid | Number of leaves removed | | | |
|---|---|---|---|---|
| | 0 | 1 | 2 | 3 |
| **1940** | | | | |
| 500 | 57.7 | 58.8 | 54.6 | 51.8 |
| 600 | 48.0 | 45.8 | 43.0 | 38.0 |
| 601 | 46.2 | 43.6 | 42.2 | 36.4 |
| 700 | 47.2 | 43.2 | 38.6 | 36.0 |
| 701 | 45.8 | 42.8 | 39.0 | 33.4 |
| Average | 49.0 | 46.8 | 43.5 | 39.1 |
| **1941** | | | | |
| 500 | 63.8 | 64.5 | 62.8 | 56.2 |
| 501 | 64.8 | 67.6 | 62.4 | 57.0 |
| 600 | 53.2 | 54.0 | 51.8 | 49.4 |
| 601 | 51.2 | 46.8 | 45.8 | 41.4 |
| 700 | 50.4 | 49.4 | 46.6 | 42.0 |
| 701 | 51.2 | 51.4 | 47.0 | 42.4 |
| Average | 55.8 | 55.6 | 52.7 | 48.0 |
| **1942** | | | | |
| 500 | 41.8 | 43.0 | 42.0 | 38.6 |
| 501 | 46.8 | 44.6 | 45.4 | 40.4 |
| 600 | 43.4 | 40.4 | 39.8 | 33.2 |
| 601 | 41.6 | 39.6 | 34.8 | 28.4 |
| 700 | 37.4 | 37.0 | 34.8 | 25.4 |
| 701 | 37.0 | 36.4 | 29.6 | 22.4 |
| Average | 41.4 | 40.2 | 37.8 | 31.4 |
| Average of averages, 1940–42 | 48.7 | 47.5 | 44.7 | 39.5 |
| Least significant differences in bu. at 5% point for average of the varieties: | | | | |
| 1940 | 2.39 | | | |
| 1941 | 2.64 | | | |
| 1942 | 2.96 | | | |
| Average, 1940–42 | 1.52 | | | |

*Minhybrid 501 was not included in 1940.

## SUMMARY

The effect on yield of seed of the removal of no leaves and of one, two, and three leaves in detasseling was compared for six hybrids, five of these being tested during three years and the other for two years only.

The removal of one leaf with the tassel when detasseling gave only a slight reduction in yield when compared with the removal of no leaves. A statistically significant difference was obtained between the

TABLE 2.—*Average yield in bushels per acre of six hybrids for the four treatments expressed in percentages of the yield of each hybrid when no leaves were removed.**

| Hybrid | 0 leaves removed | | 1 leaf removed | | 2 leaves removed | | 3 leaves removed | |
|---|---|---|---|---|---|---|---|---|
| | Bushels per acre | % | Bushels per acre | % | Bushels per acre | % | Bushels per acre | % |
| 500 | 54.4 | 100 | 55.4 | 101.8 | 53.1 | 97.6 | 48.9 | 89.9 |
| 501 | 55.8 | 100 | 56.1 | 100.5 | 53.9 | 96.5 | 48.7 | 87.3 |
| 600 | 48.2 | 100 | 46.7 | 96.9 | 44.9 | 93.2 | 40.2 | 83.4 |
| 601 | 46.3 | 100 | 43.3 | 93.5 | 40.9 | 88.3 | 35.4 | 76.5 |
| 700 | 45.0 | 100 | 43.2 | 96.0 | 40.0 | 88.9 | 34.5 | 76.7 |
| 701 | 44.7 | 100 | 43.5 | 97.3 | 38.5 | 86.1 | 32.7 | 73.2 |

*Least significant difference of percentages at the 5% point = 7.60.

removal of two leaves and no leaves for Minhybrids 601, 700, and 701. Each of the six hybrids gave a marked reduction in yield when three leaves were removed in detasseling compared with the removal of no leaves, the average difference in bushels being 9.2.

The early maturing varieties gave the greatest reductions in yield due to the removal of leaves with the tassel in detasseling. The removal of two leaves in detasseling gave only a small reduction in yield for two later hybrids that had female parents with a relatively high leaf area.

# FACTORS AFFECTING THE SUCCESS OF POLLINATION IN CORN[1]

JOHN H. LONNQUIST AND R. W. JUGENHEIMER[2]

ADVERSE weather during the critical flowering period of corn, *Zea mays* L., is perhaps one of the greatest hazards to corn production in the Great Plains area. High temperatures and extreme desiccation, or both, may blast the entire tassel or kill the pollen grains after they are shed, or may otherwise interfere with pollination by causing the silks to wilt rapidly, thus hastening the loss of their receptiveness to pollen. This interference with the pollination process is reflected in poorly pollinated ears at harvest and consequently a reduction in the yield of grain.

Previous work at the Kansas Agricultural Experiment Station (4, 5)[3] has shown that the leaves of some inbred lines and hybrids fire badly at relatively low temperatures, while others growing alongside may remain green through severe periods of drought. These studies also indicated that most hybrids that are resistant to leaf firing have an advantage in yield of grain over susceptible types during years when severe droughts occur. Corn hybrids resistant to leaf firing, however, may frequently produce low yields. It appears, therefore, that the reduction in yield may be due to interference with normal fertilization as well as injury sustained by the vegetative portion of the plant. It seemed desirable to study some of the factors affecting grain yield under drought conditions. The primary objective was to determine how seed setting in corn is affected by temperature, age of silks, and source of pollen, and how these factors are conditioned by soil moisture and the drought reaction of the material.

## MATERIALS AND METHODS

The effect of daily maximum temperatures upon seed setting was studied in 1940 and 1941 on a total of over 7,000 self-pollinations. In 1940, 15 inbred lines were grown for increase in a plot that could be irrigated with an overhead sprinkler system. Success of pollination was estimated as the percentage of the ovules on the ear developing into mature seeds. These data from more than 2,000 ears were correlated with the maximum temperature on the day of pollination. The daily temperatures were obtained from the U. S. Weather Bureau report for Manhattan, Kans. Similar data were obtained in 1941 on some 5,100 ears produced under irrigation. A wide range of breeding material was represented by including lines involved in commercial or promising experimental hybrids from 17 states. Temperature and humidity records in 1941 were obtained from

[1]Department of Agronomy, Kansas Agricultural Experiment Station, and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, cooperating. Contribution No. 346, Department of Agronomy. Received for publication June 7, 1943.

[2]Formerly Agent and Associate Agronomist, respectively, Division of Cereal Crops and Diseases.

[3]Figures in parenthesis refer to "Literature Cited", p. 933. Also, unpublished data by R. W. Jugenheimer on resistance of corn strains to leaf firing.

a recording hygro-thermograph located in the irrigated plot about 4 feet above the soil.

Six inbred lines differing in resistance to leaf firing and the 15 possible single crosses among them were used in studying the duration of silk receptivity. The material was grown on dry land and under irrigation in 1941. Plantings were made at regular intervals for a period of 1 month to insure a spread in silking of about 3 weeks. The young ear shoots were covered with parchment paper bags, before the silks appeared, to prevent natural pollination. The upper shoot was used in these studies, but all shoots were covered to prevent any possible change in the physiology of the upper shoots that might result from the fertilization of the lower ones. The number of days elapsing from the initial emergence of the silk until it was exposed to pollen was used as the silk age. Silks emerging first were held for the longest time and all were exposed on the same day to pollen from the single cross, Wf9×38-11. The harvested ears were classified into 10 grades based on the percentage of the ovules on the ear developing into mature seeds. A grade of 1 indicated 1 to 10% of seed set, a grade of 10 indicated 91 to 100%, and the eight intervening grades referred to corresponding percentages of seed set.

Three plants of each line and single cross used in the silk receptivity studies were used in studying the rate and persistance of silk growth. The amount of new growth was measured in centimeters every second day after which the silks were clipped back to the tip of the husks. This procedure was continued until no further growth occurred.

Twenty-five inbred lines grown under irrigation were used for studying the probable existence of differential fertilizing ability of pollen. On the basis of previous information on their resistance to leaf firing, 14 of these lines were classed as resistant and 11 as susceptible. Pollen of each line was placed the same day on randomly selected silks of Wf9×38-11. Each ear was graded at harvest for percentage of full seed set.

## EXPERIMENTAL RESULTS

The relative amounts of seed obtained in 1940 and 1941 on inbred lines grown under irrigation and self pollinated on days differing in their maximum temperatures are shown in Table 1. The higher average seed set in 1941 for similar temperatures was due primarily to the higher humidity during that summer. Also, temperatures during the 1941 pollinating season never exceeded 103° F. This, together with the higher humidity, probably prevented the rapid drying out of silks and pollen. In each season poor seed setting on the self-pollinated ears was significantly associated with high daily temperatures on the day of pollination. A few lines set seed well at the highest recorded temperatures, while others had low set at relatively optimum temperatures. Obviously, these better lines have a specific advantage under drought conditions.

The average percentage of seed set on lines pollinated on days of different maximum temperatures is shown by a freehand curve in Fig. 1. As an average of 2 years, seed setting ranged from 65% to only 8% when the maximum temperature on the day of pollination ranged from 80° to 110° F, respectively. The apparent failure of pollination at the higher temperatures is believed due, primarily, to

TABLE 1.—*Percentage of ovules setting seed on inbred lines of corn grown under irrigation and self pollinated on days differing in their maximum temperatures.*

| Daily maximum temperature, °F | 1940 | | 1941 | | Mean | |
|---|---|---|---|---|---|---|
| | No. of pollinations | Average seed set, % | No. of pollinations | Average seed set, % | No. of pollinations | Average seed set, % |
| 76°–80° | — | — | 186 | 64.8 | 186 | 64.8 |
| 81°–85° | 10 | 44.0 | 163 | 64.5 | 173 | 54.2 |
| 86°–90° | 388 | 26.4 | 1,536 | 65.3 | 1,924 | 45.8 |
| 91°–95° | 263 | 24.5 | 1,485 | 45.3 | 1,748 | 34.9 |
| 96°–100° | 330 | 24.9 | 1,442 | 44.1 | 1,772 | 34.5 |
| 101°–105° | 634 | 7.6 | 297 | 32.0 | 931 | 19.8 |
| 106°–110° | 440 | 8.2 | — | — | 440 | 8.2 |
| Total....... | 2,065 | — | 5,109 | — | 7,174 | — |
| Correlation coefficient. | | −0.93** | | −0.89* | | |

*Significant.
**Highly significant.

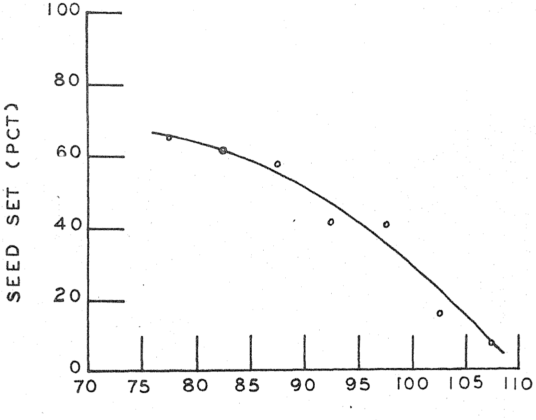


FIG. 1.—Percentage of ovules setting seed on ears of inbred lines of corn grown under irrigation and self pollinated on days differing in their maximum temperatures. Average of 1940 and 1941.

the rapid desiccation of the pollen and silks rather than to the lethal effect of high temperatures.

Pollen is subject to drying from the time of dehiscence until germination and growth into the silk is completed. Where conditions are unfavorable, the pollen grains might be easily killed by desiccation before fertilization is accomplished. White porous cup atmometers placed at various heights in a corn plot during the 1941 growing

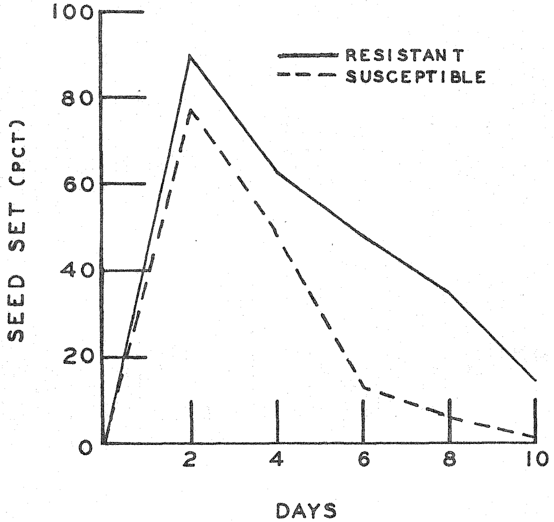


FIG. 2.—Duration of receptiveness of silks to pollen of six inbred lines of corn differing in resistance to leaf firing and compared on dry land and under irrigation, Manhattan, Kans., 1941.

season showed that evaporation decreases from the level of the tassel downward. The tassel, therefore, is subject to more severe drying than is the ear shoot or any other part of the plant. Also, because no shade is afforded the tassels, temperatures are higher there than in the silk region where considerable shading occurs.

Data on the duration of silk receptivity of inbred lines and single crosses are given in Tables 2 and 3, respectively. The mean seed set obtained from the two locations plotted graphically in Figs. 2 and 3 shows that the maximum seed set was obtained when silks were exposed to pollen 2 days after emergence and that it declined rapidly

thereafter for each additional 2-day period they were withheld from pollen. Lines and hybrids resistant to leaf firing set more seed for each silk age and their silks remained receptive longer than did those of susceptible stocks. If the leaves of resistant plants have the property of resisting water loss, there is good reason to believe that their pollen and silks also may have similar properties.

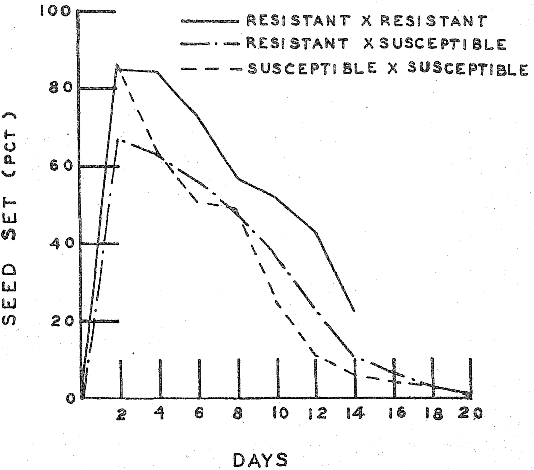


FIG. 3.—Duration of receptiveness of silks to pollen of the 15 single crosses among six inbred lines of corn differing in resistance to leaf firing and compared on dry land and under irrigation, Manhattan, Kans., 1941.

Extensive unpublished data (5) at the Kansas Experiment Station indicated a positive correlation between resistance to leaf firing and high grain yield. Thus, the available evidence indicates that in selecting material for drought resistance, i.e., on the basis of resistance to leaf firing, selection for material that has an advantage in pollination during periods of stress is accomplished also.

The effectiveness of ample soil moisture in prolonging silk receptivity differed for the inbred lines and the single crosses used in this study (Tables 2 and 3). There was no significant difference in the amount of seed set on inbred lines grown under irrigation and those grown on dry land. The single crosses, on the other hand, set significantly more seed when grown under irrigation. All three groups of crosses (resistant×resistant, resistant×susceptible, and susceptible ×susceptible) reached the limit of receptivity at 16 days under dry-

TABLE 2.—*Duration of receptiveness of silks to pollen of six inbred lines of corn differing in resistance to leaf firing and compared on dry land and under irrigation, Manhattan, Kans., 1941.*

| Location | Percentage of seed set when silks were the indicated number of days old | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2 | 4 | 6 | 8 | 10 | 12 | 14 |
| | | | Resistant Class | | | | |
| Irrigated... | 80.0 | 63.7 | 49.4 | 35.6 | 21.2 | 11.7 | — |
| Dry land... | 90.0 | 60.8 | 67.1 | 35.0 | 12.5 | 6.2 | — |
| Mean...... | 89.0 | 63.2 | 58.2 | 35.3 | 16.8 | 9.0 | — |
| | | | Susceptible Class | | | | |
| Irrigated... | 66.7 | 48.0 | 16.7 | 5.6 | 0.6 | — | — |
| Dry land... | 87.5 | 49.1 | 10.0 | 6.7 | 1.4 | — | — |
| Mean...... | 77.1 | 48.6 | 13.4 | 6.2 | 1.0 | — | — |

Analysis of Variance†

| Source of variation | D/F | Mean square |
|---|---|---|
| Leaf firing class.............. | 1 | 1381.12* |
| Silk ages.................... | 4 | 1528.90* |
| Class × silk age............... | 4 | 96.20 |
| Location.................... | 1 | 23.33 |
| Interactions: | | |
| Class × location............ | 1 | 0.24 |
| Silk age × location.......... | 4 | 28.94 |
| Error...................... | 4 | 23.97 |

*Significant.
†Analysis of variance computed from above data by converting the percentage figures to degrees. Percentage (P) = $\sin^2 \theta$.

land conditions. The summer drought became so acute at this time that all material grown on dry land fired badly within the period of a few days. This prevented the expression of any differential duration of silk receptivity which otherwise might have occurred among groups.

When the same material was grown under irrigation, however, the plants did not fire badly and the decline in silk receptivity was not nearly so rapid. Seed was set on silks up to 20 days old for crosses involving susceptible lines. The resistant × resistant crosses flowered somewhat later than plants of the other groups so that the oldest silks of this group of crosses were 14 days old when exposed to pollen. Comparisons of seed set for silks up to 14 days old show that the resistant × resistant crosses had a distinct advantage in seed set over the groups involving susceptible material.

A comparison of temperatures and humidity taken in the corn plots at both locations showed that under irrigation the maximum temperatures were lower and the relative humidity higher than in corn growing on dry land. Thus, where ample soil moisture was provided by irrigation, the severity of the surrounding environmental

TABLE 3.—*Duration of receptiveness of silks of the single crosses among six inbred lines of corn differing in resistance to leaf firing and compared on dry land and under irrigation, Manhattan, Kans., 1941.*

| Location | Percentage of seed set when silks were the indicated number of days old | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 |
| | R×R Class | | | | | | | | | | |
| Irrigated . . | 92.5 | 91.0 | 82.0 | 72.0 | 69.0 | 53.0 | 32.0 | — | — | — | – |
| Dry land. . | 77.1 | 77.9 | 64.0 | 42.9 | 35.2 | 32.4 | 12.1 | 4.3 | 0.0 | 0.0 | 0.0 |
| Mean. . . . . | 84.8 | 84.4 | 73.0 | 57.4 | 52.1 | 42.7 | 22.0 | — | — | — | – |
| | R×S Class | | | | | | | | | | |
| Irrigated . . | 93.1 | 82.5 | 73.1 | 62.0 | 52.4 | 36.2 | 24.7 | 13.4 | 6.3 | 2.1 | 0.0 |
| Dry land. . | 40.0 | 43.0 | 39.7 | 34.8 | 22.5 | 9.8 | 7.1 | 1.1 | 0.0 | 0.0 | 0.0 |
| Mean. . . . . | 66.6 | 62.8 | 56.4 | 48.4 | 37.4 | 23.0 | 15.9 | 7.2 | 3.2 | 1.0 | 0.0 |
| | S×S Class | | | | | | | | | | |
| Irrigated . . | 92.5 | 81.9 | 62.3 | 64.0 | 39.0 | 17.2 | 10.0 | 7.7 | 5.0 | 1.2 | 0.0 |
| Dry land. . | 80.0 | 46.0 | 39.3 | 34.0 | 11.7 | 5.7 | 1.7 | 0.9 | 0.6 | 0.0 | 0.0 |
| Mean. . . . . | 86.2 | 64.0 | 50.8 | 49.0 | 25.4 | 11.4 | 5.8 | 4.3 | 2.8 | 0.6 | 0.0 |

Analysis of Variance†

| Source of variation | D/F | Mean square |
|---|---|---|
| Leaf firing class. . . . . . . . . . . . . . . . | 2 | 5656.85** |
| Silk age. . . . . . . . . . . . . . . . . . . . . . . | 6 | 1462.28** |
| Class×silk age. . . . . . . . . . . . . . . . | 12 | 42.14* |
| Location. . . . . . . . . . . . . . . . . . . . . . | 1 | 2886.75** |
| Interactions: | | |
| Class×location. . . . . . . . . . . . . . | 2 | 50.21 |
| Silk age×location. . . . . . . . . . . . | 6 | 10.73 |
| Error. . . . . . . . . . . . . . . . . . . . . . . . | 12 | 15.64 |

*Significant.
**Highly significant.
†Analysis of variance computed from above data by converting the percentage figures to degrees. Percentage (P) = $\sin^2 \theta$.

conditions also was noticeably lessened. The more favorable seed setting under irrigated conditions, therefore, was due not only to the presence of sufficient soil moisture itself, but also to its effect in moderating the temperature and the evaporating power of the air around the plants.

The rate of silk growth of lines and single crosses for successive 2-day intervals was studied in 1941 in connection with the receptivity studies in an attempt to determine the rapidity with which any given region of a silk lost its receptivity after emergence from the husks. Coefficients of correlation computed between seed set and silk growth for both the inbred lines and single crosses were +0.79 and +0.83, respectively. Thus, the highest seed set (Figs. 2 and 3) and the greatest growth of silks (Figs. 4 and 5) occurred about 2 days after the

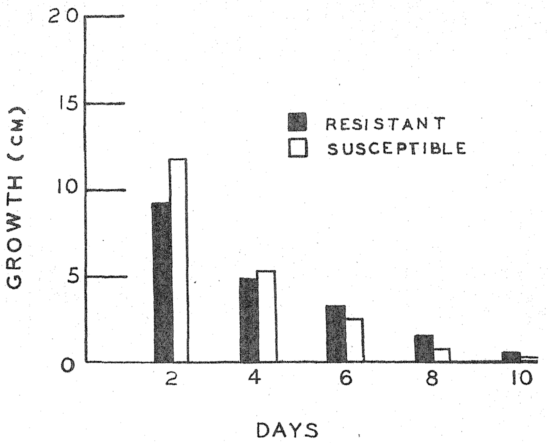


FIG. 4.—Persistance of silk growth during successive 2-day intervals of six inbred lines of corn differing in resistance to leaf firing, Manhattan, Kans., 1941.

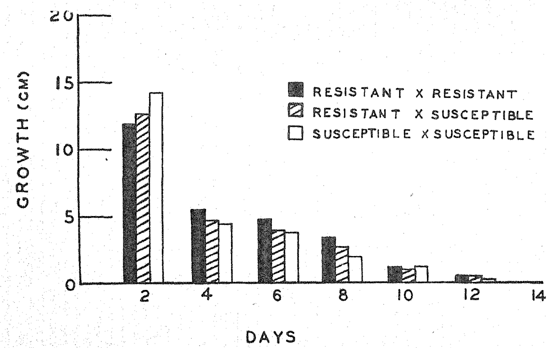


FIG. 5.—Persistance of silk growth during successive 2-day intervals for the 15 single crosses among six inbred lines of corn differing in resistance to leaf firing. Manhattan, Kans., 1941.

silks emerged from the husks. As the silk growth declined thereafter, the amount of seed set diminished correspondingly. It should be mentioned here that the entire silk brush does not and did not continue growth for the period indicated. The silks from the tip florets were the last to emerge and were apparently much slower growing than those from the central portion of the ear. These silks are responsible for the growth observed after the main brush of silks had ceased growth. Whether the apparent slower growth of the later emerging silks was due to injury sustained by clipping is not known. It may, however, be partly responsible for this behavior. The growth of the main brush of silks ceased after about 6 days following emergence. This corresponds closely with the rapid decline in seed setting when silks older than 6 days are pollinated. Apparently the loss of receptivity for any given portion of a silk is very rapid under conditions such as prevailed during the course of these studies.

Jones (3) suggested that the pollen and silks of certain lines may be incompatible when crossed. An excellent example of cross-incompatibility in corn is that of lines from two popcorn varieties used in the popcorn breeding work at Manhattan, Kans. Crosses between lines of Supergold and those from South American Varieties can be made only when South American lines are used as the pollen parent. When the reciprocal cross is attempted, no seed set results. Causal observa-

TABLE 4.—*Differential fertilizing ability of pollen of 25 inbred lines of corn when placed on silks of the single cross, Wf9×38–11.*

| Resistant to leaf firing | | Susceptible to leaf firing | |
|---|---|---|---|
| Line | Percentage seed set | Line | Percentage seed set |
| K 201A | 82.5 | Ind. 66–24 | 89.0 |
| K 148 | 72.5 | K 26 | 79.0 |
| K 17 | 72.5 | K 14 | 75.0 |
| K 8 | 71.0 | Iowa Bl 349 | 75.0 |
| K 55 | 70.0 | K 151 | 65.0 |
| Ind. 38–11 | 67.0 | K 20 | 62.0 |
| K 130 | 65.0 | K 214 | 60.0 |
| U. S. 187–2 | 63.0 | K 5 | 51.0 |
| Iowa L 317 | 58.0 | K 131 | 45.0 |
| K 10 | 50.0 | K 249 | 42.5 |
| K 153 | 41.0 | K 61 | 37.0 |
| Ind. Wf9 | 32.0 | | |
| K 18 | 14.0 | | |
| K 167 | 12.0 | | |
| Mean | 55.2 | Mean | 61.9 |

Analysis of Variance

| Source of variation | D/F | Mean square |
|---|---|---|
| Leaf firing class | 1 | 21.17 |
| Lines | 24 | 18.84** |
| Error | 91 | 5.37 |

**Highly significant.

tions in the breeding nursery over a period of years have suggested the possibility that pollen of some lines is able to affect fertilization more readily than others when crosses with a given female parent are made. Data obtained in 1941 and presented in Table 4, although obtained from a small sample of each of 25 lines, tend to bear out this observation. The seed set produced by the pollen of individual lines used on the silks of Wf9×38–11 ranged from 12 to 89% of the receptive ovules available. Ample pollen was applied to the silks and it is felt that the observed differences in seed set are not due to deficiencies of viable pollen. Analysis of variance showed that the differences in seed set among lines were highly significant. There was no apparent relation between the resistance or susceptibility of the lines to leaf firing and the ability of their pollen to fertilize the ovules of Wf9×38–11. Differences between the two groups of lines, i.e., resistant and susceptible, to leaf firing were not expected, however, as the pollinations were made during a period of optimum temperatures.

The observations on drought-resistant strains reported by Jenkins (2), Sayre (6), and Jugenheimer (4) and the work of Heyne and Brunson (1) show that drought resistance is definitely inherited and indicate the possible achievements in breeding for drought resistance. Moreover, the observations reported in this paper further indicate that breeding for drought resistance can materially assist in lessening hazards to yield caused by incomplete pollination during drought periods.

## SUMMARY

Factors affecting seed setting in corn were studied during the summers of 1940 and 1941.

Significant negative correlations were obtained between high temperatures and seed setting on inbred lines when self-pollinated. Some lines set seed well at the highest recorded temperatures while others set few seeds at relatively optimum temperatures. As an average of 2 years, seed setting ranged from 65 to 8% when the maximum temperature on the day of pollination ranged from 80° to 110° F, respectively.

Maximum seed setting was obtained when silks were exposed to pollen 2 days after emergence, and it declined rapidly thereafter for each additional 2-day period that pollen was withheld from the silks. Lines resistant to leaf firing, as well as the single crosses among them, set more seed throughout the life of the silks and remained receptive longer than did the susceptible lines and crosses. Loss of receptivity was more rapid in the inbred lines than in the single crosses.

Adequate soil moisture provided by irrigation, together with the associated lower temperatures and higher humidity, was effective in prolonging silk receptivity.

Highly significant positive correlations were obtained between rate of silk emergence and percentage of seed set for successive 2-day intervals following initial silk emergence. Lines and hybrids whose silks remain receptive for longer periods have a specific advantage under drought conditions.

Pollen of 25 lines placed the same day on randomly selected silks of the single cross Wf9×38-11 gave highly significant differences in resulting seed set. The differences obtained are thought to be due to varying degrees of cross-incompatibility existing between the pollen of various lines and the silks of the seed parent.

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# SELECTION IN SELF-POLLINATED LINES OF *BROMUS INERMIS* LEYSS., *FESTUCA ELATIOR* L., AND *DACTYLIS GLOMERATA* L.[1]

H. K. Hayes and A. R. Schmid[2]

THE breeding of grasses in Minnesota was initiated in the spring of 1936. Native and introduced species and varieties of cultivated grasses were grown at the central and branch experiment stations alone and in various combinations with other grasses and legumes, and harvested as hay or clipped to simulate pasture, in order to learn what species and varieties were of greatest promise in Minnesota. No recently introduced species or varieties that were studied appeared as desirable as the cultivated grasses grown previously. It was decided, therefore, to confine the breeding studies largely to smooth brome, *Bromus inermis* Leyss., meadow fescue, *Festuca elatior* L., orchard grass, *Dactylis glomerata* L., crested wheatgrass, *Agropyron cristatum* (L) Beauv., and Kentucky bluegrass, *Poa pratensis* L. Previous studies by Schultz (4) with orchard grass and Murphy (1)[3] with crested wheatgrass and reviews of literature have been published. Myers (2,3) summarized briefly the literature relating to self- and cross-fertility in grasses.

The breeding studies have been organized under two main divisions. One method used with several grasses may be outlined briefly as follows: A nursery of several hundred spaced plants for each species worked with is studied for at least two seasons and from 80 to 100 plants of greatest promise are selected. During this period notes on individual plants are taken on plant habit, disease reaction, and yield. Clonal progenies of the first plants selected are studied in replicated rows or beds and about 20 of the clonal lines that have the best record of performance are selected. Open-pollinated seed is obtained from these selected clones by cutting all other clones in the trial before pollination. The seed of the clones selected is mixed and increased in an isolated seed plot. This seed furnishes the basis for a second cycle of selection and the desirability of the new strain is determined by field trials at the central and branch stations. Individual plant nurseries from such seed increases were started in 1942 and the performance studies in field plots were sown in the spring of 1943.

Another phase of the breeding studies has consisted of selection in self-pollinated lines of the same origin as the plants selected for clonal trials. There is a wide difference of opinion among grass breeders regarding the desirability of this method. To prove at all feasible it is essential that seed production under self-pollination conditions be sufficiently good to furnish the necessary material for selection. The selfed lines must be sufficiently vigorous so that they may be handled conveniently and for a sufficient number of generations in order to

[1]Contribution from the Division of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minn. Paper No. 2094, Scientific Journal Series, Minnesota Agricultural Experiment Station. Received for publication June 11, 1943.

[2]Chief of Division and Assistant Professor, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 943.

make it possible to select for specific characters. With crested wheatgrass (1) seed setting under a bag was so low that selection in selfed lines did not seem practical, while with orchard grass (4) seed setting under conditions of self pollination was relatively good.

The present paper includes a study of the effects of self fertilization and selection with smooth brome, meadow fescue, and orchard grass. Studies of $F_1$ crosses will be reported also for brome grass and for orchard grass.

## MATERIALS AND METHODS

Data were taken mainly on individual plants that were grown in the field, with sufficient space between plants to maintain their identity, from seedling progenies started in flats in the greenhouse during early spring. The second season's growth was used in most of the studies.

Only plants that appeared to excel in the characters considered to be of greatest importance were selected for self pollination. The characters studied included vigor, habit of growth, resistance to disease, and winter injury. Vegetable parchment bags, 18 by 3 by 2½ inches, were used to cover the panicles. They were tied to supporting stakes by string inserted in an eyelet in the base of the bag. Usually, five panicles per plant were enclosed, the stems being covered with cotton, the bag tied over the stems and also to the stake. Bags were examined as seemed necessary, particularly after a severe storm, and those that showed serious injury to the stems were discarded.

One- and two-year selfed progenies, $S_1$ and $S_2$, and a check from commercial seed were used to study the effects of controlled pollination and selection with brome grass and meadow fescue. A limited study of $F_1$ crosses was made in the brome grass. With orchard grass studies were made of $F_1$ crosses in comparison with $S_1$ to $S_4$ selfed lines. Two replications in randomized blocks, with from 12 to 20 spaced plants per row plot, were used in the studies. Data were taken on the plot basis at approximately the hay cutting stage for average total dry weight per plant for one or two cuttings.

Leaf spot reaction in brome grass caused primarily by *Selenophoma bromigena* (Sacc.) (Sprague and Johnson) was studied, each plant being placed in one of the classes 1 to 5, ranging from light to very heavy infection. Winter injury was studied in orchard grass and in meadow fescue by placing individual plants in one of five classes, class 1 with no winter injury and classes 2 to 5 representing a range from slight winter injury to complete winterkilling, respectively.

When insufficient seedlings were available for replicated plots, the progenies with a smaller number of plants were arranged systematically and check rows from commercial seed were grown nearby. Progenies with 10 or more plants per row plot have been used to increase the number of progenies studied. Means for such progenies, however, are less accurate than for the replicated studies.

Seed setting was determined by threshing the plants individually. It was difficult with this material to estimate seed production at all accurately by inspection. Consequently, a measured portion of the threshed and cleaned head material was taken, seedling production determined in a germinator, and the seedlings counted. Open-pollinated heads were handled in a similar manner, seed production being expressed as F over I, where F is the number of seedlings from open pollination and I represents seedlings obtained from selfed seed of the same plants.

Analyses of variance were calculated for the replicated trials for average

total yield of dry matter per plant, reaction to leaf spot, and winter injury, and the standard deviation of a difference between two means was calculated. Highly significant differences were obtained between lines for yield with each of the three species, for leaf spot reaction in brome grass, and for winter injury in meadow fescue and orchard grass. The results are given in frequency tables for the means of inbred lines and crosses using classes of plus and minus 1, 2, 3, etc., times the standard error of a difference from the mean of the commercial check. Average values for yield and other characters for the inbred lines and $F_1$ crosses are given in percentage of the commercial check as 100 computed by averaging the actual means for the lines of similar treatment.

## EXPERIMENTAL RESULTS

A summary of seed setting under a bag for plants grown from commercial seed and from inbred lines for three species of grasses and from $F_1$ crosses in orchard grass is given in Table 1.

TABLE 1.—*Seed setting studies under bag isolation in Bromus inermis, Festuca elatior, and Dactylis glomerata.*

| Material | Year | Number of plants | | Mean F/I |
|---|---|---|---|---|
| | | With seeds | Without seeds | |
| | | *Bromus inermis* | | |
| Commercial | 1937 | 45 | 2 | 126.7 |
| Commercial | 1939* | 58 | 8 | 15.8 |
| Commercial | 1939 | 33 | 35 | 51.1 |
| Commercial | 1940 | 5 | 1 | 18.2 |
| Commercial | 1942 | 2 | 7 | 41.0 |
| $S_1$ | 1940 | 23 | 67 | 18.5 |
| $S_1$ | 1942 | 35 | 23 | 17.9 |
| $S_2$ | 1942 | 21 | 22 | 20.1 |
| | | *Festuca elatior* | | |
| Commercial | 1940 | 19 | 2 | 10.2 |
| Commercial | 1942 | 30 | 1 | 7.4 |
| $S_1$ | 1940 | 155 | 66 | 16.0 |
| $S_2$ | 1942 | 103 | 23 | 14.0 |
| | | *Dactylis glomerata* | | |
| Commercial | 1942 | 13 | 5 | 25.9 |
| $F_1$ | 1942 | 88 | 33 | 29.0 |
| $S_1$ and $S_2$ | 1942 | 20 | 6 | 41.8 |
| $S_3$ and $S_4$ | 1942 | 35 | 7 | 19.4 |

*Data from the Waseca Branch Experiment Station. Other data from University Farm, St. Paul.

During the years which include 1937, 1939, 1940, and 1942 for brome grass, there was a wide range in seed setting under a bag as shown by mean values of F over I ranging from 15.8 to 126.7. Plants of brome grass with average values of F over I of 50 usually set sufficient seed for selection purposes. The same clonal lines of brome grass were selfed at University Farm in 1937 and in 1939 and at Waseca in 1939. No apparent relation existed for seed setting of

clonal lines when only a single bag was used at each location and year for each clonal line. At Waseca in 1939, 8 bagged plants out of 64 produced no seed, while at University Farm for the same year 35 out of 68 produced no seed. Less than half the plants in $S_1$ and $S_2$ lines produced seed under a bag. In these years it would be correct to conclude with brome grass that somewhat less than half of the bagged plants produced sufficient seed to furnish material for selection in self-pollinated lines. In 1941 seed setting under bag isolation with several grasses including brome and meadow fescue was almost a complete failure.

During 1937, plants of meadow fescue from commercial seed of three different origins were selfed. Sixty-one plants, with 10 panicles per plant enclosed in a bag, produced 20 or more seeds ranging to several hundred, 31 plants produced less than 20 seeds per plant, all 92 selfed plants producing some seed. Data for 1937 are not summarized in the table as no comparisons for open-pollinated panicles are available. Data in 1940 and 1942 from $S_1$ and $S_2$ lines lead to the conclusion that seed setting under a bag in meadow fescue was somewhat better for plants from commercial seed than for relatively vigorous plants in $S_1$ and $S_2$ lines. Seed setting under a bag with meadow fescue was considerably higher, on the average, than for brome and somewhat higher than for orchard grass.

Previous data have been given by Schultz for seed setting in bagged orchard grass at University Farm, St. Paul, and Myers has shown conclusively that inherited differences in seed setting between inbred lines are present in orchard grass. The bagged plants of $F_1$ crosses in 1942, given in Table 1, did not set seed as well, on the average, as plants of inbred lines that had been selfed for either three or four generations. Seed setting in orchard grass under a bag has been sufficiently good at University Farm, St. Paul, so that it has proved relatively easy to obtain sufficient selfed seed for practical purposes.

Data are given in Tables 2 and 3, respectively, for yield and leaf spot reaction in brome grass. As was explained above, the effects of selfing were studied in randomized blocks of 12 to 20 plants per plot with two replications when sufficient seedlings were available. Data are presented also for systematic trials of single plot comparisons when 10 or more plants per line were grown. Most of the data in Tables 2 and 3 are from trials made the second season after the plots were established. Data are given for the first cutting only during the third season after the plots were established for 20 $S_1$ lines.

The total yield of two cuttings for 11 $S_2$ inbreds was 100.2 in terms of the commercial check as 100. Seven $S_2$ inbreds in single plot trials gave an average yield of 118.6%. The first cutting of 20 $S_1$ selfed lines averaged 92.6% in yield. The selfed lines differed widely in yielding ability. They yielded as well, on the average, as the commercial check. Most of the selfed material originated from an old pasture in Martin County, Minnesota, and the commercial check is from Canadian-grown seed. It is somewhat surprising that the selfed material yielded so well. The lines were much more uniform in growth habit than the check.

For leaf spot reaction the individual plants were placed in five

TABLE 2.—*Frequency distribution for average yield of two cuttings of selfed lines of creeping brome in yield classes of + or −1, 2, 3, etc., times the S.E.$_{diff.}$ from the yield of the commercial variety, 1942.*

| Type of test | Material | Yield classes | | | | | | | | Average yield in % of check as 100 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | −3 | −2 | −1 | 0 | +1 | +2 | +3 | +5 | |
| Replicated | $S_1$ | – | 1 | 1 | – | – | 1 | – | – | 95.3 |
| | $S_2$ | 1 | 4 | 1 | 1 | 1 | – | 2 | 1 | 100.2 |
| Systematic | $S_2$ | – | – | 1 | 2 | – | 2 | 2 | – | 118.6 |
| | commercial | – | – | 1 | 1 | 1 | – | – | – | 100.0 |
| Replicated* | $S_1$ | – | 4 | 6 | 4 | 6 | – | – | – | 92.6 |

*1st cutting only.

TABLE 3.—*Frequency distribution for mean leaf spot reaction of selfed lines in creeping brome in classes of plus or minus 1, 2, 3, etc., times the S.E. $_{diff.}$ from the leaf spot reaction of the commercial variety, 1942.*

| Type of test | Material | Leaf spot reaction classes | | | | | | | | | Average in % of check as 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | −5 | −4 | −3 | −2 | −1 | 0 | 1 | 2 | 3 | |
| Replicated | $S_1$ | | | | | | 1 | | 2 | | 111.5 |
| | $S_2$ | 3 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | | 74.6 |
| Systematic | $S_2$ | | 2 | 1 | | 2 | 1 | 1 | | | 82.8 |
| | commercial | | | | | | 3 | | | | 100.0 |
| Replicated* | $S_1$ | | | | 6 | 2 | 9 | 1 | 1 | 1 | 94.8 |

*1st cutting only.

classes, as has been explained. The S.E.$_{diff.}$ between two means was 0.3. Highly significant differences were obtained in leaf spot reaction. $S_2$ selfed lines gave a mean value of 74.6% in comparison with the check as 100, showing that they were, on the average, rather resistant to injury by leaf spot. Selection in self-pollinated lines appears to be a desirable method of producing a resistant variety.

Previous studies by Tsiang (5) with brome grass, using selfed lines that were obtained from the studies reported in this paper, proved very conclusively that reaction to leaf spot was an inherited character. Tsiang also gave evidence for wide differences between selfed lines in beta-carotene content, yield, and other characters of agronomic importance. Crosses were made by Tsiang between individual plants of different $S_1$ lines. These were grown in comparison with clonal increases of the parent plants. The results for yield and leaf spot reaction are given in Table 4.

Two replications of clonal lines of SB 2, 3, 5, 6, 7, 8, 9, and 10 were grown but only single plots were grown of the $F_1$ crosses and selfed progenies of SB 2 and 6. The clonal lines gave yields ranging from 81.7 to 130 in terms of the check as 100 while the $F_1$ crosses ranged from 126.5 to 220.9. The number of plants available is too small to

TABLE 4.—*Comparison of clonally propagated one-year selfed lines of creeping brome and their $F_1$ crosses for yield and leaf spot reaction in percentage of the yield and leaf spot reaction of the commercial variety as 100.*

| Selfed line or cross | In percentage of commercial variety as 100 | | Average number of plants per plot |
|---|---|---|---|
| | Yield | Leaf spot | |
| $SB_2$ | 103.5 | 85.7 | 6 |
| $SB_3$ | 113.5 | 78.6 | 8 |
| $SB_2 \times 3$ | 197.0 | 71.4 | 3 |
| $SB_3 \times 2$ | 150.1 | 114.3 | 7 |
| $SB_2$ | 103.5 | 85.7 | 6 |
| $SB_8$ | 91.0 | 39.3 | 7 |
| $SB_2 \times 8$ | 126.5 | 100.0 | 4 |
| $SB_5$ | 81.7 | 89.3 | 5 |
| $SB_7$ | 122.9 | 139.3 | 7 |
| $SB_5 \times 7$ | 158.0 | 121.4 | 7 |
| $SB_7 \times 5$ | 167.3 | 117.9 | 4 |
| $SB_5$ | 81.7 | 89.3 | 5 |
| $SB_8$ | 91.0 | 39.3 | 7 |
| $SB_5 \times 8$ | 142.0 | 121.4 | 5 |
| $SB_7$ | 122.9 | 139.3 | 7 |
| $SB_8$ | 91.0 | 39.3 | 7 |
| $SB_7 \times 8$ | 176.4 | 107.1 | 32 |
| $SB_8 \times 7$ | 186.9 | 75.0 | 9 |
| $SB_9$ | 130.0 | 82.1 | 8 |
| $SB_{10}$ | 125.9 | 89.3 | 8 |
| $SB_9 \times 10$ | 220.9 | 85.7 | 7 |
| $SB_6$ | 131.7 | 53.6 | 6 |
| $SB_6$–1 | 121.7 | 85.7 | 5 |
| $SB_2$ | 103.5 | 85.7 | 6 |
| $SB_2$–1 | 135.6 | 103.6 | 7 |
| Commercial | 100 | 100 | 16 |

draw definite conclusions regarding the mode of inheritance of leaf spot reaction. Reciprocal crosses of $SB_2$ and 3, two resistant clones, gave widely different results. In the cross $SB_9 \times 10$ the parent clones and $F_1$ progeny were resistant. Incidentally, this is the highest yielding $F_1$ cross. Several crosses were as susceptible, or more so, than the susceptible parent. Two second generation inbreds averaged higher in leaf spot infection than their parental clones. It is probable that leaf spot infection may have been due to several different causal organisms in these studies.

$S_2$ inbred lines of meadow fescue were grown in randomized blocks with two replications. Group 1 was tested in 20 plant plots and group 2 in 12 plant plots with a commercial check grown in each group. Data on average yield and average winter injury for these 49 $S_2$ lines are given in Tables 5 and 6.

TABLE 5.—*Frequency distribution for mean yield of $S_2$ lines of meadow fescue in yield classes of plus and minus 1, 2, 3, etc., times the S.E.$_{diff.}$ from the yield of the commercial variety.*

| Type of test | Material | Yield classes | | | | | | | Average yield in percentage of check as 100 |
|---|---|---|---|---|---|---|---|---|---|
| | | −5 | −4 | −3 | −2 | −1 | 0 | +1 | |
| Group 1, 20-plant plots | $S_2$ | | 3 | 7 | 8 | 6 | | 1 | 63.6 |
| Group 2, 12-plant plots | $S_2$ | 3 | 4 | 8 | 6 | 3 | | | 45.7 |

TABLE 6.—*Frequency distribution for average winter injury of $S_2$ lines of meadow fescue in classes of plus or minus 1, 2, 3, etc., times the S. E.$_{diff.}$ from the commercial variety.*

| Type of test | Material | Winter injury classes | | | | | Average winter injury in percentage of check as 100 |
|---|---|---|---|---|---|---|---|
| | | 0 | +1 | +2 | +3 | +6 | |
| Group 1......... | $S_2$ | 10 | 5 | 3 | 6 | 1 | 154.0 |
| Group 2......... | $S_2$ | 6 | 8 | 7 | 3 | | 194.4 |

Data were averaged for each selfed line and the commercial check on the basis of the number of plants that were alive the previous fall. Consequently, those lines with the more severe winter injury yielded much less than the check which gave an average mean for winter injury of 1.2. Of the 49 $S_2$ lines that were compared with the check, from commercial northern grown seed, one $S_2$ line yielded somewhat more than the check and this same line in $S_1$ trials exceeded the check in yield. Nine other inbred lines yielded nearly as well as the check. Group 1 gave an average yield of 63.6 in terms of 100 as the check, while group 2 yielded 45.7% as much as the check.

The individual plants were placed as has been explained in five classes for winter injury, ranging from 1 with no injury to 5 for complete killing. The calculated standard errors of a difference for winter injury were 0.56 and 0.48, respectively, for groups 1 and 2. Sixteen of the $S_2$ lines were highly winterhardy in these studies. It is possible with this material that the reduction in vigor that was obtained as a result of selfing may have been responsible in part for the greater winter injury of many of the selfed lines than for the commercial check.

Studies with orchard grass consisted of a relatively small number of selfed lines, 39 $F_1$ crosses and a commercial check. Data were taken, as in meadow fescue, on the basis of plants alive the previous fall. The $F_1$ crosses were produced in this case by growing two clonal $S_1$ lines together, for each cross, in an isolated plot. In several cases the $F_1$ crosses were compared directly with $S_2$ inbreds obtained by selfing the clonal $S_1$ parents. The plants of each $F_1$ cross were uniformly alike and it seemed probable that most of the seed produced in these crossing plots was from cross pollination. Data are given on yield and winter injury in Tables 7 and 8.

TABLE 7.—*Frequency distribution for mean yield of selfed lines and $F_1$ crosses of orchard grass in classes of plus or minus 1, 2, 3, etc., times the S.E.$_{diff.}$ from the yield of the commercial variety, 1942.*

| Type of test | Source | Yield classes | | | | | | | | Average yield in percentage of check as 100 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | −4 | −3 | −2 | −1 | 0 | +1 | +2 | +3 | |
| Group 1 | $S_2$ | – | 1 | – | 1 | 2 | – | – | – | 67.5 |
| | $S_3$ | – | 1 | | 2 | 2 | – | – | – | 66.2 |
| | $S_4$ | – | – | – | 1 | 3 | – | – | – | 90.8 |
| | $F_1$ | – | – | – | 1 | 2 | 6 | 4 | 1 | 132.9 |
| Group 2 | $S_3$ | 1 | – | 1 | – | – | – | – | – | 53.9 |
| | $F_1$ | 1 | 1 | 2 | 5 | 9 | 7 | – | – | 94.9 |

TABLE 8.—*Frequency distribution for average winter injury of selfed lines and $F_1$ crosses of orchard grass in classes of plus and minus 1, 2, 3, etc., times the S.E.$_{diff.}$ from the commercial variety, 1942.*

| Type of test | Source | Winter injury classes | | | | | | | Mean winter injury in percentage of check as 100 |
|---|---|---|---|---|---|---|---|---|---|
| | | −3 | −2 | −1 | 0 | +1 | +2 | +3 | |
| Group 1 | $S_2$ | – | 1 | – | 1 | 1 | – | 1 | 108.1 |
| | $S_3$ | – | 2 | 1 | – | – | 1 | 1 | 97.4 |
| | $S_4$ | 2 | 2 | – | – | – | – | – | 56.5 |
| | $F_1$ | 8 | 4 | 1 | 1 | – | – | – | 59.2 |
| Group 2 | $S_3$ | – | – | – | 1 | – | 1 | – | 121.4 |
| | $F_1$ | – | 8 | 11 | 3 | 1 | 2 | – | 79.6 |

In group 1 four $S_2$ lines yielded 67.5% of the commercial check, five $S_3$ lines 66.2%, and four $S_4$ lines 90.8% of the check. Fourteen $F_1$ crosses gave an average yield of 132.9% of the check. In group 2 there were two $S_3$ lines, 25 $F_1$ crosses, and the check. The two $S_3$ lines yielded 53.9% as much as the check, while the 25 $F_1$ crosses yielded 94.9% of the check, on the average.

Several of the 3- and 4-year selfed lines in group 1 were less severely winter injured than the check. The average winter injury of four $S_4$ lines was 56.5% and of 14 $F_1$ lines was 59.2%. The 25 $F_1$ lines in group 2 were less severely injured on the average than the check.

## DISCUSSION

Self pollination and selection have been carried on with several species of grasses during five different seasons. Seed setting under bag isolation was somewhat greater for meadow fescue than for orchard or brome grass. Nearly complete failure to obtain selfed seed was obtained in one year only when brome and meadow fescue were studied. During the remaining four years, sufficient selfed seed was obtained relatively easily with *Bromus inermis*, *Festuca elatior*, and *Dactylis glomerata* to make selection in selfed lines feasible, providing

it proves to be worthwhile as one phase of the breeding program. In order to have a fair chance of success two or three times as many plants should be selfed as will be needed. With the material available in these studies there has been little or no difficulty of selecting several plants in promising selfed lines that appeared equally desirable in the characters for which selection was practiced.

The relative value of selection in selfed lines, as a tool for the isolation of desired combinations of characters, can be determined only in comparison with other methods of selection. The ultimate proof of a breeding method is its value in the breeding of improved varieties. It seems probable that the isolation of clonal and selfed lines, their test for combining ability, and their combination in crosses to produce a synthetic variety, or to produce single or double crossed seed as has been outlined by Tysdal, *et al.* (6) for alfalfa, will prove valuable also in grasses.

There would seem to be a real opportunity to achieve marked improvement in forage grasses by several methods of selection. The necessary genetic diversity can be obtained eventually by the interchange of material between breeders who are working on the problem of improvement of the same species. Selection in selfed lines practiced for only a few generations seems a logical and efficient method of isolating relatively vigorous lines with the extent of homozygosity in important characters that is desirable.

## SUMMARY

1. A considerable amount of selfed seed by bag isolation was obtained during four out of five years with brome grass, meadow fescue, and orchard grass. In order to obtain sufficient seed for selection it was necessary to bag about three times as many plants as could readily be used as parents for the production of selfed lines.

2. Plants of good vigor were selected for selfing. After two years or more of selection in selfed lines a few lines in each of the three species were obtained that were as vigorous as the commercial check.

3. From replicated studies in randomized blocks it was concluded that the selfed lines differed significantly in yield in all three species for reaction to leaf spot in brome grass and for winter injury in orchard grass and meadow fescue.

4. Eleven $S_2$ lines of brome grass in replicated trials yielded about the same, on the average, as the commercial check and about half of these were significantly lower than the commercial variety in leaf spot reaction. From studies of a few plants in each of several crosses between $S_1$ clones, the yield of $F_1$ crosses ranged from 126.5% of the commercial check to 220.9%.

5. Approximately 20 out of 49 $S_2$ lines of meadow fescue were significantly more severely injured by winterkilling than the commercial check. One inbred line yielded somewhat more than the check during both the $S_1$ and $S_2$ generations. The average yield of the 49 inbreds was 54.7% of the check.

6. Several 2- to 4-year selfed lines of orchard grass were as vigorous as the commercial check, although selfing on the average for 2 to

4 years led to a reduction in vigor. The 49 $F_1$ crosses gave about the same yield as the commercial check. There was a significant difference between selfed lines and between $F_1$ crosses in both yield and winter injury.

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# VARIATION IN TANNIN CONTENT OF CLONAL AND OPEN-POLLINATED LINES OF PERENNIAL LESPEDEZA[1]

R. E. STITT[2]

SERICEA lespedeza, *Lespedeza cuneata* (Dum. de Cours) G. Don, a perennial species introduced from eastern Asia, has been found to be well adapted to the soil and climatic conditions of the southern United States. This species contains a considerable amount of tannin, a substance adversely affecting palatability. In order to plan a breeding program for the improvement of sericea lespedeza, it seemed desirable to study the variations of tannin within clones and individual plants from various seed sources.

The questions which this study has been designed to answer are twofold. First, are differences in the tannin content inherited? And second, can sufficient variation be found to warrant low-tannin selections being made? In the course of this study factors that may be correlated with the tannin content and may otherwise have selection value in an improvement program also have been determined.

## REVIEW OF LITERATURE

The literature dealing with feeding trials of sericea lespedeza has been adequately reviewed by Clarke, *et al.* (3).[3] Both feeding and pasture trials have given variable or conflicting results. It is evident that some factor is often present which lowers the palatability, as judged by the intake of roughage and effect on the animal.

Clarke, *et al.* (3) identify the tannin in sericea lespedeza as belonging to the catechol group of tannins (2) from its reactions of an olive green color with iron-alum solution, a precipitate with bromine water, and being completely precipitated by formaldehyde in the presence of hydrochloric acid. They investigated

[1]Cooperative investigations between the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering; the Hides, Tanning Materials, and Leather Division, Eastern Regional Research Laboratory, Bureau of Agricultural and Industrial Chemistry, U. S. Dept. of Agriculture; and the North Carolina Department of Agriculture and the North Carolina Agricultural Experiment Station at Statesville, N. C. Part of a thesis presented to the faculty of the graduate school of the University of Minnesota, December 1941, in partial fulfillment of the requirements for the degree of doctor of philosophy. Published with the approval of the Director of the North Carolina Agricultural Experiment Station as Paper No. 153 of the Journal Series. Received for publication January 21, 1943.

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[3]Figures in parenthesis refer to "Literature Cited", p. 954.

the tannin in the leaves and stems of sericea harvested at weekly intervals from May 29 to July 31, 1935, at Arlington Farm, Va. There was an increase from 7.5 to 18.0% of tannin in the leaves as the season progressed. The total tannin content of the stems was very low and varied from 1.0 to 1.6%. This variation in the stems was not correlated with the age of the plant.

The plants decreased in leafiness as the tannin content of the leaves increased. This created a balance whereby after the first of June the percentage of tannin in the whole plant was essentially constant. The percentage of tannin in the whole plant ranged from 6.1 on May 20 to 9.0 on June 20 and 8.0 on July 31. The dry matter in the fresh green plant increased progressively from 33.6 to 56.4 per cent.

Stitt and Clarke (5) made tannin analyses on samples of sericea lespedeza harvested at Statesville, N. C., at 14-day intervals from May 5 to October 20, 1936, from plots not previously harvested during the season. The tannin in the leaves increased from 6.3% on May 5 to 15.0% on June 30, after which there was a progressive decrease to 7.8% on October 6 and increase to 8.8% on October 20. The tannin in the stems varied from 1.8 to 2.9%. In general, the tannin content of the whole plant varied with that of the leaves.

Clarke, *et al.* (3) found that the results of precipitating the tannin with formaldehyde and hydrochloric acid differed from those of the hide-powder method by a constant factor and state, "under certain circumstances, therefore, this method might be used as a convenient procedure for determining the approximate tannin content of *Lespedeza sericea*."[4]

## MATERIALS AND METHODS

The material used for the clonal study was selected from 83 different lots representing introductions from Asia and several selections made in the United States. The plants were grown in spaced plantings in the field. Six plants were selected in 1937 and increased by vegetative cuttings.

These clones were transplanted to the field in June 1938 and arranged in randomized blocks with five replications of each selection. Each plot consisted of 20 plants set 1 foot apart in a $4 \times 5$ foot rectangle. The outside plants of each plot were left as borders.

Five seed sources of perennial lespedeza, including introductions and selections made by the U. S. Dept. of Agriculture, also were chosen for study on the variability in tannin content and other characters between strains and individual plants.

Just prior to harvesting the plants of the selected clones and strains the height of each shoot was recorded in inches. The plants were cut 2 inches above the ground level, weighed immediately, and then air-dried in open paper bags in the shade. The leaves were separated from the stems for leafiness determinations and were then ground fine enough in a hammer mill to pass through a 1-mm screen.

Two methods of tannin analysis were used in the course of this study. The hide-powder method[5] of the American Leather Chemists Association, with modifications in procedure as outlined by Stitt and Clarke (5), was used in determin-

[4]*Lespedeza sericea* has been used in most of the literature for the species herein designated as *L. cuneata* according to the international rules of nomenclature. Sericea or sericea lespedeza is used as a common name.

[5]The hide-powder method determinations were made by the Hides, Tanning Materials, and Leather Division, Eastern Regional Research Laboratory, Bureau of Agricultural and Industrial Chemistry, U. S. Dept. of Agriculture.

ing the tannin content of the clones. In order to compare methods, determinations on the clones and individual plants were made also by a precipitation method, using formaldehyde and hydrochloric acid to precipitate the tannin. This method saves one-half the time of the operator and can be used on smaller samples.

The total correlation of the methods was .61 which exceeds the 1% point. Analysis of variance revealed that the interaction between methods and clones was not significant, indicating that the two methods of analysis gave similar evaluations of the clonal tannin content.

## EXPERIMENTAL RESULTS

### STUDIES WITHIN AND BETWEEN CLONES

The mean squares from the analyses of variance of the total tannin, average height, number of shoots, leafiness, dry matter, and yield of the six *Lespedeza cuneata* clones are given by crops in Table 1. All of the characters measured showed highly significant differences between some of the clones with the exception of dry matter in the second crop. Block differences were significant for dry matter in the first crop and for tannin, height, dry matter, and yield in the second crop, showing that local control, in the form of randomized blocks, led to reduced error. These significant block differences indicate that soil variation has considerable effect on the development of sericea lespedeza. The relatively great variation in tannin between clones indicates that selection of clones from different seed sources should be very effective in isolating clones lower in tannin content.

TABLE 1.—*Mean squares from analyses of variance of data from Lespedeza cuneata clones.*

| Variation due to | D. F. | Tannin | Height | Number of shoots | Leafiness | Dry matter | Yield |
|---|---|---|---|---|---|---|---|
| First Crop, May 25, 1939 | | | | | | | |
| Blocks | 4 | 0.90 | 1.26 | 6.64 | 0.48 | 3.66* | 0.02 |
| Clones | 5 | 14.35** | 80.18** | 23.58** | 125.47** | 12.77** | 0.559** |
| Error | 20 | 0.60 | 2.10 | 3.72 | 2.85 | 1.19 | 0.017 |
| Total | 29 | | | | | | |
| Second Crop, July 10, 1939 | | | | | | | |
| Blocks | 4 | 4.42** | 2.52* | 21.87 | 1.79 | 3.83* | 0.051** |
| Clones | 5 | 6.76** | 17.85** | 138.07** | 27.93** | 2.56 | 0.079** |
| Error | 20† | 0.37 | 0.63 | 17.13 | 3.05 | 1.29 | 0.006 |
| Total | 29† | | | | | | |

*Exceeds the 5% point.
**Exceeds the 1% point.
†Three samples were lost during analysis and the tannin data interpolated. The degrees of freedom for tannin were 17 and 26 for error and total, respectively.

Percentage of total tannin in the leaves, height, number of shoots, leafiness, dry matter, and yield of the *Lespedeza cuneata* clones is given in Table 2.

TABLE 2.—*Total leaf tannin, height, number of shoots, leafiness, dry matter, and yield of Lespedeza cuneata clones.*

| Clone No. | Total leaf tannin, % | Height, inches | Shoots per plant | Leafiness, % | Dry matter, % | Yield, tons per acre |
|---|---|---|---|---|---|---|
| | | | First Crop, May 25, 1939 | | | |
| 3-18 | 10.6 | 19.8 | 9.4 | 56.4 | 32.4 | 1.06 |
| 3-21 | 11.0 | 19.1 | 11.9 | 56.0 | 33.1 | 1.14 |
| 4-22 | 6.6 | 9.3 | 12.3 | 67.9 | 32.5 | 0.42 |
| 5-32 | 9.5 | 13.9 | 6.6 | 63.1 | 36.5 | 0.37 |
| 5-44 | 10.5 | 14.3 | 8.9 | 64.2 | 35.0 | 0.49 |
| 8-21 | 10.8 | 18.1 | 8.4 | 57.3 | 34.3 | 0.70 |
| Average | 9.9 | 15.8 | 9.6 | 60.9 | 34.0 | 0.70 |
| Sig. dif. 5% point | 1.0 | 1.9 | 2.5 | 2.2 | 1.4 | 0.17 |
| 1% point | 1.4 | 2.6 | 3.5 | 3.0 | 2.0 | 0.24 |
| | | | Second Crop, July 10, 1939 | | | |
| 3-18 | 12.2 | 15.1 | 22.5 | 67.3 | 38.5 | 0.85 |
| 3-21 | 11.5 | 13.5 | 26.4 | 68.3 | 38.9 | 0.80 |
| 4-22 | 10.4 | 10.2 | 33.0 | 73.0 | 39.5 | 0.69 |
| 5-32 | 13.2 | 14.9 | 20.3 | 69.0 | 40.4 | 0.67 |
| 5-44 | 13.5 | 13.0 | 30.9 | 71.4 | 40.1 | 0.75 |
| 8-21 | 12.9 | 11.7 | 21.4 | 72.4 | 39.8 | 0.49 |
| Average | 12.3 | 13.1 | 25.7 | 70.2 | 39.6 | 0.71 |
| Sig. dif. 5% point | 0.8 | 1.0 | 5.6 | 2.3 | 1.5 | 0.10 |
| 1% point | 1.1 | 1.4 | 7.4 | 3.1 | 2.0 | 0.14 |
| | | | Average of Two Crops | | | |
| 3-18 | 11.4 | 17.4 | 15.9 | 61.8 | 35.5 | 0.96 |
| 3-21 | 11.3 | 16.3 | 19.1 | 62.1 | 36.0 | 0.97 |
| 4-22 | 8.4 | 9.7 | 22.6 | 70.4 | 36.0 | 0.55 |
| 5-32 | 11.3 | 14.4 | 13.4 | 66.4 | 38.4 | 0.52 |
| 5-44 | 12.0 | 13.7 | 19.9 | 67.8 | 37.6 | 0.62 |
| 8-21 | 11.8 | 14.9 | 14.9 | 64.9 | 37.0 | 0.60 |
| Average | 11.1 | 14.4 | 17.6 | 65.6 | 36.5 | 0.70 |
| Sig. dif. 5% point | 0.8 | 1.1 | 3.8 | 1.6 | 1.1 | 0.09 |
| 1% point | 1.1 | 1.0 | 5.2 | 2.2 | 1.5 | 0.13 |

Each clone contained less tannin in the first than in the second crop. The differences were significant for all clones except 3-21. In the first crop, the leaves of clone 4-22 were significantly lower in tannin than the leaves of the other clones. Clone 5-32 was intermediate, and the other clones were high in leaf tannin.

The difference between clones was not the same in the two crops, however, clone 4-22 was the lowest in percentage of tannin for both

crops. Clone 3–21 was the highest in tannin in the first crop and next to the lowest in the second. Clone 5–32 was next to the lowest in the first crop and next to the highest in the second.

It is interesting to note that clone 4–22, with the lowest amount of tannin, was the leafiest clone in this test. Its yield, however, was low due to its lower height.

There were significant differences in height between the clones in both crops; however, they were not as pronounced in the second as in the first crop. On the basis of height, clones 3–18, 3–21, 5–44, and 8–21 had slower rates of growth in the second than in the first crop. Clones 4–22 and 5–32 grew relatively faster in the second crop. The average height of the first crop was 2.7 inches greater than that of the second.

In sericea lespedeza, the shoots of the first crop develop from crown buds located from just above the soil line to an inch or more beneath the surface. After the first growth of the season is removed, the subsequent growth is produced from buds near the ends of the stubble. Each of these stems usually produce several new shoots.

The shoots from crown buds have a greater diameter than the shoots forming the aftermath. This partly accounts for the greater proportion of stems in the first crop.

The average of the yields for the first and second crops were similar. The highest yielding clones in both crops were 3–18 and 3–21, and the lowest yielding were 4–22 and 5–32.

Correlation coefficients of the different characters were calculated from the analysis of covariance to determine the degree of association between clones for all characters studied. These were calculated separately for the two crops and for crop totals and are given in Table 3.

The tannin content of the clones increased with height in both crops. The first crop was taller than the second at the time of harvest and the tannin content was higher in the second than in the first crop, thus reversing the relationship of high tannin with tall plants which was evident within the crops. Clones 4–22 and 5–32 were slightly taller in the second than in the first crop, being exceptions to this relationship.

Tannin decreased as leafiness increased; however, the correlation was significant only in the first crop. The tannin-leafiness relationship was not independent of height. Leafiness decreased as height increased. This inverse relationship was due to an increase in the weight of the stems without a proportional leaf increase. Stem growth was largely in a longitudinal direction.

Clones 3–18 and 3–21 were vigorous and assurgent and very similar in habit of growth. Both recovered rapidly after the first crop was removed. Clone 8–21 was similar for the first growth period but made a slow recovery after the harvest. Based on general appearance and behaviour 5–32 and 5–44 can be placed in a second group with slow growth of the first crop followed by vigorous recovery. The growth of the shoots was spreading in both periods. Clone 4–22 was erect in habit and slow growing, with numerous shoots.

TABLE 3.—*Correlation of different characters between clones of Lespedeza cuneata.*

| | Leaf tannin | Height | Shoots | Leafiness | Dry matter |
|---|---|---|---|---|---|
| | | First Crop | | | |
| Height | 0.89 | — | — | — | — |
| Shoots | −0.37 | −0.15 | — | — | — |
| Leafiness | −0.82 | −0.98 | 0.04 | — | — |
| Dry matter | 0.19 | −0.17 | −0.82 | 0.27 | — |
| Yield | 0.61 | 0.85 | 0.36 | −0.90 | −0.65 |
| | | Second Crop | | | |
| Height | 0.97 | — | — | — | — |
| Shoots | −0.49 | −0.63 | — | — | — |
| Leafiness | −0.14 | −0.90 | 0.50 | — | — |
| Dry matter | 0.54 | −0.15 | −0.01 | 0.50 | — |
| Yield | −0.22 | 0.49 | 0.27 | −0.68 | −0.59 |
| | | Crop Totals | | | |
| Height | 0.77 | — | — | — | — |
| Shoots | −0.64 | −0.62 | — | — | — |
| Leafiness | −0.59 | −0.96 | 0.50 | — | — |
| Dry matter | 0.37 | −0.14 | −0.44 | 0.34 | — |
| Yield | 0.24 | 0.73 | 0.03 | −0.83 | −0.72 |

5% point for significance of r = 0.81; 1% point = 0.92.

## STUDIES WITHIN AND BETWEEN STRAINS

The source of the seed of the five strains of perennial lespedeza chosen for study originally were introductions from Japan. All had been more or less selected since being introduced.

All of these strains represented open-pollinated seed. The amount of self- or cross-fertilization in lespedeza has not been studied carefully. It has been a general opinion of those working with lespedeza that there is a high percentage of self-pollination. The amount of variation that has been observed would indicate some cross-pollination. The writer has one procumbent line in which 14.6% of assurgent plants were obtained from the open-pollinated seed of one procumbent plant. The parent plant was surrounded by assurged plants. Selfed seed from this one plant produced all procumbent plants, indicating that foreign pollen was responsible for the assurgent plants.

The different lots of seed were planted in the greenhouse in January 1937 in rows 2 inches apart. The seedlings were transplanted to the field on August 11, 1937. They were set in plots containing four rows with 12 plants per row and spaced 1 foot apart each way. The plots were arranged in random blocks with five replications. The outside rows of each plot were treated as borders.

The individual plants of F. C. Nos. 19284, 12087, 04730, and F. P. I. No. 65903 (*Lespedeza cuneata*) were harvested for analysis on June 7 and of F. C. No. 19285 (*L. latissima*) on July 12, 1939.[6]

[6]F. C. and F. P. I. refer to numbers assigned, respectively, by the Divisions of Forage Crops and Diseases, and Plant Exploration and Introduction, both of the Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture.

The tannin content of the leaf material from these strains was determined by the formaldehyde-precipitate method.

Mean squares from the analyses of variance for the five strains of the two perennial species of lespedeza are given in Table 4. There were highly significant differences between strains for all the measurements except yield and significant differences between strains for yield. A comparison of errors a and b indicates that there is more variation between strains than within strains.

TABLE 4.—*Mean squares from analyses of variance of formaldehyde-precipitate, height, number of shoots, leafiness, dry matter, and yield per plant for four strains of Lespedeza cuneata and one strain of L. latissima.*

| Variation due to | D. F. | Formaldehyde-precipitate, % | Height | Number of shoots | Leafiness, % | Dry matter, % | Yield, tons per acre |
|---|---|---|---|---|---|---|---|
| Blocks.. | 4 | 12.88 | 190.08* | 138.83 | 228.09* | 50.17 | 2.87 |
| Strains.. | 4 | 901.77** | 2741.77** | 2520.63** | 4227.74** | 818.13** | 3.54* |
| Error (a) | 16 | 15.61 | 41.08 | 90.03 | 71.33 | 48.22 | 0.96 |
| Plots.... | 24 | — | — | — | — | — | — |
| Error (b) | 464† | 8.55 | 14.58 | 38.33 | 22.84 | 12.47 | 0.40 |
| Total... | 488† | — | — | — | — | — | — |

*Exceeds the 5% point.
**Exceeds the 1% point.
†11 degrees of freedom dropped because of missing plants.

The average measurements and their standard deviations of formaldehyde-precipitate, height, number of shoots, leafiness, dry matter, and yield for four strains of *Lespedeza cuneata* and one strain of *L. latissima* are given in Table 5.

There were significant differences in percentage of formaldehyde-precipitate in the leaves among each of the five strains, except F. C. 04730 and 19285. F. C. 19285 (*Lespedeza latissima*) was not harvested until a month later than the other strains and so may have changed in tannin content during the interim.

The strains showed considerable difference in type. The plants of F. C. 19285 were short, averaging only 8.9 inches even though harvested at a later date than the other strains. Plants of this strain produced a larger number of shoots than the others and were almost procumbent in habit. F. C. 12087 was the shortest of the assurgent strains. F. C. 19284, 04730, and F. P. I. 65903 were all tall growing. F. P. I. 65903 produced a relatively higher number of shoots than the other assurgent strains.

The extremely low tannin plants were non-vigorous. A large proportion of these plants showed signs of abnormal growth which may have been due to environmental factors such as injury during the process of transplanting from the greenhouse to the field or adverse soil conditions. In each strain there were a few plants lower in tannin and more vigorous than average. The plants of both of

TABLE 5.—*Means and standard deviation for formaldehyde-precipitate, height, number of shoots, leafiness, dry matter, and yield of four strains of Lespedeza cuneata and one strain of L. latissima.*

| Strain No. | Formaldehyde-precipitate, % | | Height in inches | | Number of shoots per plant | | Leafiness, % | | Dry matter, % | | Yield, tons per acre | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | S. D. | Mean | S. D. | Mean | S. D. | Mean | S. D. | Mean | S. D. | Mean | S. D. |
| 04730* | 16.9 | 3.65 | 19.8 | 4.61 | 12.1 | 5.40 | 60.5 | 6.08 | 38.8 | 3.65 | 1.01 | 0.69 |
| 12087* | 14.3 | 3.69 | 15.2 | 4.70 | 12.7 | 5.02 | 67.6 | 4.88 | 38.2 | 5.24 | 0.87 | 0.72 |
| 19284* | 16.6 | 2.37 | 22.2 | 4.22 | 10.9 | 4.44 | 57.9 | 4.80 | 37.8 | 3.88 | 1.02 | 0.61 |
| 19285† | 22.4 | 2.01 | 8.9 | 1.88 | 22.5 | 8.29 | 74.5 | 3.55 | 44.4 | 2.90 | 0.94 | 0.54 |
| 65903* | 18.6 | 2.46 | 19.4 | 2.93 | 18.8 | 6.93 | 63.6 | 4.02 | 37.7 | 1.67 | 1.36 | 0.57 |
| Least significant difference at | | | | | | | | | | | | |
| 5% point | 1.2 | | 1.9 | | 2.8 | | 2.5 | | 2.1 | | 0.29 | |
| 1% point | 1.6 | | 2.6 | | 3.9 | | 3.5 | | 2.9 | | 0.40 | |

*Harvested June 7, 1939.
†Harvested July 12, 1939.

these low-tannin groups require further testing in order to determine their value.

The genetic relationship of F. C. 19285 to the other strains is not known. Morphologically it differs widely enough to have been given the species name *Lespedeza latissima* (Mats.) Nakai. Its growth was much shorter than the other strains, yet it was the highest in tannin content. This reversal from the positive height correlation found within strains may have been partly due to a progressive increase in tannin with season as F. C. 19285 was harvested 35 days later than the others.

Total correlations within strains between all possible combinations of the five different measurements are given in Table 6. Plants with a large number of shoots were taller than those with a small number of shoots. Leafiness decreased as height increased and so was also inversely correlated with number of shoots and yield.

Dry matter and yield correlations were negative and significant for all the strains. Thus, the higher the yield, the higher the moisture content. This tendency of the non-vigorous plants to be less succulent may have been due to stunting of some of the smaller plants. The leaves of these plants also showed more or less yellowing during the entire growing period.

The correlation coefficients between height, number of shoots, and yield with the formaldehyde-precipitate values are all positive and highly significant. The tannin content of the strains is associated with the general vigor of the plants.

The formaldehyde-precipitate values increased as leafiness decreased in strains F. C. 04730, 12087, and 19284. Dry matter and

TABLE 6.—*Correlation of different characters within strains of Lespedeza cuneata and L. latissima.*

| | Strains | | | | |
|---|---|---|---|---|---|
| | 04730 | 12087 | 19284 | 19285 | 65903 |
| Formaldehyde precipitate with | | | | | |
| Height | 0.65 | 0.68 | 0.41 | 0.34 | 0.31 |
| No. of shoots | 0.65 | 0.45 | 0.48 | 0.22 | 0.08 |
| Leafiness | −0.30 | −0.69 | −0.36 | −0.16 | −0.13 |
| Dry matter | −0.40 | −0.18 | −0.56 | −0.03 | −0.08 |
| Yield | 0.60 | 0.58 | 0.53 | 0.25 | 0.33 |
| Height with | | | | | |
| No. of shoots | 0.62 | 0.43 | 0.43 | 0.45 | 0.26 |
| Leafiness | −0.56 | −0.80 | −0.79 | −0.55 | −0.70 |
| Dry matter | −0.34 | −0.24 | −0.14 | −0.14 | −0.33 |
| Yield | 0.81 | 0.81 | 0.70 | 0.84 | 0.72 |
| No. of shoots with | | | | | |
| Leafiness | −0.46 | −0.49 | −0.41 | −0.41 | −0.38 |
| Dry matter | −0.33 | −0.07 | −0.16 | −0.29 | −0.37 |
| Yield | 0.87 | 0.72 | 0.76 | 0.81 | 0.57 |
| Leafiness with | | | | | |
| Dry matter | 0.37 | 0.32 | 0.08 | 0.38 | 0.34 |
| Yield | −0.57 | −0.74 | −0.63 | −0.34 | −0.47 |
| Dry matter with | | | | | |
| Yield | −0.35 | −0.25 | −0.22 | −0.24 | −0.45 |

5% point for significance of $r = 0.20$; 1% point $= 0.26$.

formaldehyde-precipitate values were inversely correlated in F. C. 04730 and 19284.

Regression lines of height in inches and percentage of formaldehyde-precipitate are shown in Fig. 1. The differences among these regressions were tested by the method outlined by Snedecor (4) and gave an F value of 5.07, indicating highly significant differences. Thus, the rate of change in tannin per unit change in height was not the same for all strains.

From Fig. 1 it is evident that strains F. C. 04730 and 12087 were similar in rate of change in tannin per unit change in height. The differences among the regressions of strains F. C. 19284, 19285 and F. P. I. 65903 were tested and found to be nonsignificant. The strains thus fell into two groups for rate of change in tannin per unit change in height. The strains with the higher rate of change were more variable in both height and tannin content than those with the lower rate.

## SUMMARY

1. Six clones of sericea lespedeza were studied at Statesville, N. C., for inherent differences in tannin content of the leaves, height, number of shoots, leafiness, dry matter, and yield as harvested on May 25 and July 10, 1939.

2. Relatively great variation in leaf tannin between clones was

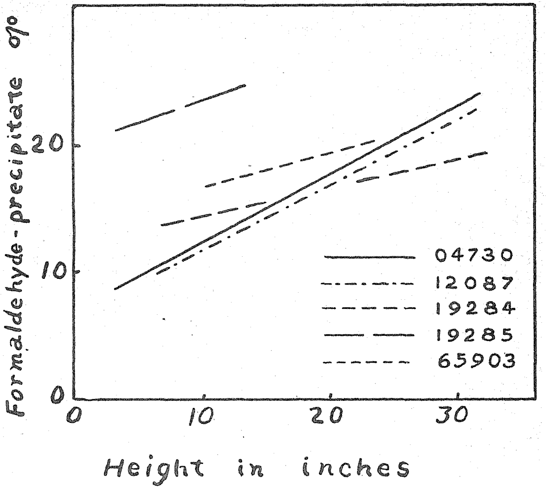


FIG. 1.—Regression lines of height in inches and percentage formaldehyde-precipitate of four strains of *Lespedeza cuneata* and one strain of *L. latissima*.

found, indicating that selection of clones from different seed sources should be very effective in isolating clones lower in tannin content.

3. One clone (4–22) was found to be inherently lower in percentage of tannin than the other clones, but probably not low enough to be of value for farm use. This clone was low in yield also.

4. The percentage of tannin in the clones was much higher in the second than in the first crop. The differences may have been due to a progressive seasonal increase. The type of growth was fundamentally different for the two crops. The second crop produced from two to three times as many shoots per plant as the first crop.

5. Inherent differences in type of growth were found. The six clones followed four patterns of growth, namely, vigorous and assurgent for both growth periods; assurgent with vigorous growth during the first period but slow recovery in the aftermath; and erect in habit with slow growth.

6. The tannin content of the clones increased with height. In the first crop tannin increased as leafiness decreased. Leafiness decreased as height increased in both the first and second crops as stem growth was largely in a longitudinal direction. Leafiness decreased as yield increased.

7. By use of a short method (formaldehyde-precipitate), the leaves of 100 plants of each of four strains of *Lespedeza cuneata* and one strain of *L. latissima* were analyzed for tannin. These plants were from open-pollinated seed.

8. Some of the strains contained a number of plants low in tannin. Tannin was directly related to height and yield in all strains and to number of shoots in four of the strains. An indirect association was present between tannin and leafiness in three strains and between tannin and dry matter in two strains.

9. As indicated by their standard deviations three of the five strains were lower in variability of tannin content than the other two.

10. The strains showed considerable difference in type. *Lespedeza latissima* (F. C. 19285) was relatively short and almost procumbent in habit. The *L. cuneata* strains varied in height but were all relatively tall and all assurgent.

11. From a study of the differences between the regressions of height on percentage formaldehyde-precipitate of the strains, it was found that the strains fell into two groups for rate of change in tannin per unit change in height.

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# A CHART FOR EVALUATING AGRICULTURAL LIMESTONE[1]

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THE need of a simple method for evaluating agricultural limestone on a basis of probable activity and cost of lime active over different periods after incorporation into the soil has long been recognized. A plan for evaluation, suggested by the junior author, was published by Bear and Allen (2).[3] The basis is size composition data furnished by a complete sieve analysis. A ground limestone is considered to be made up of a number of size classes, as defined by standard sieves, of particles with known mean diameters (d) and similar average shape. Dissolution should act upon all particles alike in a given time, removing from each a shell of material uniform in thickness, and so reducing the diameters of all particles by a constant amount, $a$ unit, up to the point of disappearance. The proportion (R) of the material in each size class which remains after the mean diameter (d) of all the particles in the size class has been reduced by $a$ unit will be $R = \left(\frac{d - a}{d}\right)^3$. The proportion of the weight of each size class which has been active will be 1–R, a measure of the activity of the size class. The comparative value of any ground limestone of similar dissolution characteristics over the given time will then be the sum of the products, percentage of each size class in the limestone times a factor (1–R) appropriate to that size class and time.

The accuracy of an evaluation based on this idea depends primarily upon knowledge of the rate of attack upon limestone in a typical acid soil under field conditions. Upon this depends the value $a$, required for calculating 1–R. Obviously, $a$ is not to be considered an absolute value, to be observed by direct measurements on limestone particles or by similar means. It is a calculated value which can be derived from data on disappearance of carbonate after an application at a known rate of a narrowly defined size class of limestone to a representative acid soil under conditions resembling those of practical liming. In an experiment of this kind, where the mean diameter of the limestone size class used is d and R is the fraction of the carbonate applied which remains after a certain time, $a = d(1 - \sqrt[3]{R})$. For such experiments to furnish a value of $a$ which will be practically useful, it is important that the rate of application be adjusted to the soil's ability to decompose limestone, the so-called lime requirement. But since there would be required a time inconveniently long to approach satisfaction of the full lime requirement by medium or coarser size classes applied at practical rates, the aim in our experiments has been to apply limestone

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[3]Figures in parenthesis refer to "Literature Cited", p. 966.

as a median size class at moderate field rates, such that the lime requirement will be as nearly as possible half satisfied by the limestone decomposed at the end of the experimental period. These major experiments were supplemented by others on a smaller scale, applying coarser size classes of limestone at heavier and finer at lighter rates, as required by differences in particle diameters, to prove the point that under constant conditions the value of $a$ is constant for particles of all size classes. Observations on the rates of activity at intervals during the comparatively short experimental periods were the basis of estimates of probable further activity over longer times.

## PROCEDURE

Experiments to establish values for $a$ have been conducted on six of the principal soil types of Ohio on which liming is important, at each location with separates, predominantly No. 50 to 70, from six commercial limestones widely used in Ohio. Duplicated frames 24 inches square and 8 inches deep were set in the ground and each filled with 200 pounds of the air-dried and screened soil previously removed, with which the weighed amount of the sized limestone had been thoroughly mixed at 2 to 4 tons to the acre rates. The soil in these frames exposed to natural conditions, uncultivated but with weeds allowed to grow, was sampled at intervals for 2 years and the carbonate remaining determined.

Data from eight or nine samplings from each of 12 frames for each limestone were thus obtained. The multiplicity of data permitted plotting and selection of probable values on a mathematical basis. The limestones ranged from a high calcium rock from Michigan to the nearly pure dolomite quarried at Woodville, Ohio, with four stones of intermediate magnesium contents and purities from other quarries in Ohio.

These experiments were supplemented by others in which small amounts of soil with the proper amounts of limestone separates of various size classes and varied nature, from approximately 50% purity to pure calcite and pure dolomite, were enclosed in cloth bags and buried to plow depth in the field for recovery intact after suitable times.

## RESULTS

Values for $a$ indicated by these experiments varied consistently, inversely with the ratio dolomite to calcite in the limestone and directly with time as expected from theoretical considerations, including the factor of diffusion through soil. The latter is the basis of extension to longer periods, 4 and 16 years, than were actually covered by the experiments. The 16-year period was selected as possibly approximating an extreme value for the length of the liming cycle. It is not to be inferred that this is necessarily the time an adequate liming may be expected to be economically effective. It was concluded from this work that the calcite and dolomite components of limestone vary in activity in the soil, but the content of earthy impurities has practically no influence except as a diluent reducing the total neutralizing power.

The initial activity of an impure limestone is not less than that of a pure limestone with similar ratio calcium to magnesium, of the same fineness, when applied to furnish the same total amounts of

calcium and magnesium carbonates. Dolomitic limestones are less active than high-calcium limestones of the same size composition, but the difference is important only with short time periods and coarse materials. With fine materials and over longer times, the generally higher total neutralizing powers of high-magnesium limestones may cause them to excel in activity high-calcium limestones otherwise similar.

The values for $a$ shown in Table 1 were calculated from the experimental data. They are believed to be applicable under average conditions of liming soils in Ohio and the time periods considered are those of greatest practical importance. A table of values of $1-R$ was calculated therefrom for use as previously outlined. However, this method requires considerable further calculation as well as a detailed knowledge of the size composition of the material, not always available. An easier method of evaluation is desirable even at some sacrifice in accuracy. It may be pointed out that practical liming operations never result in the perfect distribution of limestone throughout the soil that must be assumed in evaluation, so a method of moderate precision should suffice.

TABLE 1.—*Values for a applicable under Ohio conditions.*

| Kind of limestone | Three months inch | One year inch | Four years inch | Sixteen years inch |
|---|---|---|---|---|
| Calcitic.......... | 0.0022 | 0.0046 | 0.0069 | 0.0082 |
| Dolomitic........ | 0.0011 | 0.0030 | 0.0055 | 0.0074 |

Observations on the size composition of commercial agricultural limestone grades, ranging from coarse screenings to superfine kiln-dried limestone, have shown a marked trend toward a similar pattern of size distribution in all these products. When plotted in the proper manner, percentages passing standard sieves vs. diameters of the size classes so defined, the points representing the great bulk of each grade tend to fall on or near straight lines. Two studies of size composition of all samples that could be secured from Ohio producers, respectively in 1932 (5) and 1941, have led to the same conclusion. So far as value as a soil neutralizer is concerned, the size composition of practically all commercial agricultural limestone can be represented with insignificant error by a simple visual estimate as a straight line on a chart. This fact makes possible the construction of an alinement chart to avoid most of the calculation required in evaluation. More important, it makes possible an evaluation from limited sieve data, even to the extent that knowledge of percentage passing but one sieve, e. g., No. 100, will probably be sufficient for practical purposes.

## AN EVALUATION CHART

Fig. 1 is an evaluation chart for agricultural ground limestone designed for the graphical method of evaluation outlined. The horizontal spaces thereon represent U. S. standard sieves and are

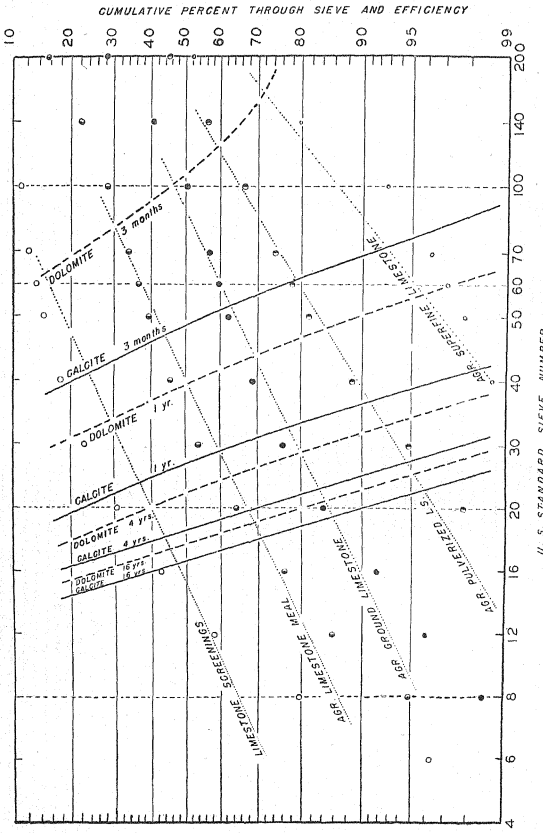


FIG. 1.—Evaluation chart for agricultural ground limestone.

numbered correspondingly at the bottom. These spaces are proportionate to the logarithms of the mesh diameters of successive sieves and, since the latter are in the constant ratio square root of 2, are equal. An exception is the No. 60 sieve which is included because it is specified by the Ohio liming materials law. The mesh diameter of this member of the double set of testing sieves is related to those of the successive sieves of the single set by the constant fourth root of 2, so it has a half space on the scale. This and the other sieves specified by the Ohio law are indicated by the vertical short dashed lines on the chart. The positions of other sieve lines are shown by short lines at the top and bottom of the chart, with the U. S. standard sieve numbers at the bottom.

Referring to the horizontal lines on the chart indicating divisions on the vertical axis of the plotting, the corresponding scale of percentages at the right side of the chart indicates both cumulative[4] or total percentages of the limestone passing the various sieves and the probable percentage efficiency or activity in soil neutralization of the material as a whole. The vertical spacing is on a probability scale, primarily to increase the tendency for the points representing size composition to fall on straight lines (1). Another advantage is that this scale, compressed at the middle and symmetrically expanded at the ends, automatically increases the precision of readings for the finer and more valuable grades of limestone. The omission of a 100% point from this scale is required by considerations of probability.

The heavy diagonal lines in the general direction upper left to lower right and marked "Calcite 16 years", etc., are the loci of solutions to problems of activity of pure limestones composed of a regular succession of particle sizes, conforming with the trend previously observed (5) in commercial limestone grades. The locations of these "efficiency lines" were determined in the following way. In the preliminary stages of developing the chart, with the system of coordinates described, it was observed that the straight lines taken for present purposes to represent average size compositions of the grades (further described in the next paragraph) tended to intersect at a point off the chart. From this point about 30 lines were drawn, well distributed over the chart, to represent imaginary grades of limestone with the regularity in size composition noted. The size composition of each such imaginary grade was read from the per-

[4]In making sieve analyses, the usual procedure is to determine separately the percentages held between sieves, each such percentage corresponding to a size class defined by the mesh diameters of the two sieves, one just passing and the other retaining that portion of the sample. These data are used in the arithmetical method of evaluation. But in plotting sieve analysis data, it is necessary to consider the total percentage of the sample which passes each sieve; this is called the cumulative percentage passing, because it is the sum of the percentage held between that and the next finer sieve plus the percentages found on all the finer sieves and the pan. It is the percentage that would pass if the sieve in question was the only one used in testing. Sieve analyses of agricultural limestone are required by the laws of Ohio and some other states to be stated in the cumulative form. For example, 95% passes sieve No. 8, 65% passes sieve No. 20, 35% passes sieve No. 60, and 28% passes sieve No. 100, is a statement in the required form.

centage values at intersections with the vertical sieve lines on the chart. From the size composition data so derived and the 1–R factors from $a$ values previously established, the activities of a pure high calcium limestone and a pure dolomite were calculated, each for the four time periods considered. On each line representing an imaginary grade, the points where these calculated activities corresponded to the percentage scale were marked. The corresponding points of each set on all the lines were found to fall on a line or smooth curve, which were then drawn in and the hypothetical grade lines were finally erased from the chart. It will be noted that there are four pairs of efficiency lines, referring to the time periods 16 and 4 years, 1 year and 3 months. The solid line of each pair refers to calcitic and the dashed line to dolomitic limestones, as marked.

The diagonals of the second set, lightly dotted straight lines in the general direction lower left to upper right, are the "fineness lines" corresponding to average grades of commercial agricultural limestones on the Ohio market in 1941. The actual size composition of each average grade is shown by the points printed on the chart, those of each set distinctively marked. Efficiencies read from the percentage scale, corresponding to the intersections of average fineness lines with the efficiency lines, agree in all cases with those calculated from 1–R factors and the size compositions indicated by the respective sets of points, according to the arithmetical method previously outlined.

With this alinement chart it is possible to calculate graphically the probable activity of any ground limestone applied at practical rates to acid soils, provided the limestone does not depart too widely from average size composition characteristics. This condition will be met if the significant size composition points (those corresponding to important size classes occurring in the material) fall reasonably near a straight line when plotted on the chart, so that the fineness line can be fitted to these points without difficulty by visual estimation. A brief study of the relation of a similar average fineness line to the respective set of points, both as printed on the chart to show the average size characteristics of a representative grade of agricultural limestone, will develop judgment in this respect. All commercial and home ground agricultural limestones so far examined have shown sufficient regularity in size distribution for evaluation without great errors. In nearly all comparisons between graphical and arithmetical evaluation of actual samples, agreement was within 5%. In this use of the chart, the variables size composition and time are considered. The readings so secured may be further utilized to include in a simple manner chemical composition as a third variable.

## USE OF CHART FOR AGRICULTURAL LIMESTONE EVALUATION

This chart may be used to estimate the activity or effective value of any ground limestone of known fineness and chemical composition at the end of a specified time after application to the soil, at a practical rate consistent with the soil's ability to decompose the amount of limestone applied. The idea of evaluation includes the

assumption of uniform incorporation to plow depth, to secure the best distribution possible with the fineness of the material, in a definitely acid soil under climatic and soil conditions similar to those in Ohio. It is believed that, with judgment, different materials may be compared and proportionate values assumed for shallower or surface applications under similar conditions. Effective value is stated as calcium carbonate equivalent (CCE), percentage of the weight of liming material applied.

1. Judge the general nature of the limestone from the ratio, total neutralizing power expressed as percentage calcium carbonate equivalent (TNP) divided by percentage magnesium (Mg), hereinafter indicated TNP/Mg.
   a. If TNP/Mg exceeds 50, consider the limestone to be calcite.
   b. If TNP/Mg is less than 10, consider it to be dolomite.
   c. If TNP/Mg ranges 10–50, consider the neutralizing values of both carbonate minerals in the limestone.
2. Plot the sieve data for the limestone on the chart, marking temporarily on each vertical line representing a sieve the total or cumulative percentage passing that sieve, according to the scale of percentages at the right side. Fit the "fineness line" to the point or points, with regard to the following:
   a. If only a single point is known (preferably for a fine sieve, for example, No. 100), the fineness line is defined by laying a transparent straightedge or stretched thread to pass through the point and have a slope consistent with that of the nearest of the fineness lines printed on the chart, representing average commercial limestone grades.
   b. If two or more points are known, not falling exactly on a line with the proper slope, most weight should be given points representing the finer and more active part of the material, as a rule. The fineness line in that event should fall on or between points representing finer sieves, and progressively farther from points representing coarser sieves, as the latter increase in coarseness, as may be required to give the line a proper slope. An exception to the foregoing may be materials predominantly coarse and very deficient in the fraction passing No. 100, for which percentage passing a coarser sieve, e. g., No. 12, may better indicate the average fineness. In such cases, the fineness line is given the slope normal to the coarser grade with a similar percentage passing the sieve in question. It should be noted that of points for coarse sieves, all representing high percentages passing, only the point for the finest of these sieves is significant.
   c. With a sufficient number of significant points in linear relation on the chart, the fineness line is defined without consideration of slope.
3. From the intersection of the fineness line with the calcite and /or dolomite efficiency line appropriate to the time to be considered, as printed on the chart, read the "efficiency" of calcite (*c*) and/or dolomite (*d*) as a percentage on the scale at the right.

4. Referring to the three cases considered in item 1, calculate the "activity" of the limestone as percent calcium carbonate equivalent (CCE) as follows:
   a. $c \times$ TNP/100 = activity of calcitic limestone.
   b. $d \times$ TNP/100 = activity of dolomitic limestone.
   c. For a limestone containing important amounts of both calcite and dolomite, first calculate the neutralizing powers of the component carbonate minerals, from the percentage magnesium (Mg) and total neutralizing power as percentage calcium carbonate equivalent (TNP):
      Mg $\times$ 8.23 = DNP, neutralizing power of dolomite in the limestone.
      TNP − DNP = CNP, neutralizing power of calcite in the limestone.
      ($c \times$ CNP/100) + ($d \times$ DNP/100) = activity of a magnesian limestone.
5. Analyses of agricultural limestone usually refer to air-dry or moisture-free material, whereas that shipped in bulk may contain up to 10% or more moisture. For a material with M % moisture, the activity calculated on the dry basis is multiplied by (100 − M)/100 to secure the activity of the material as purchased or applied to the land.

"Activity" is a comparable value which can be calculated for any limestone of known size and chemical composition, and for some other materials,[5] enabling comparison of values offered by various liming materials at different prices per ton applied to the field and over different time periods.

*Example 1.*—A dealer guarantees the following for his ground limestone:

| Sieve analysis | | Chemical analysis (dry basis) | |
|---|---|---|---|
| Pass No. 8 | 99% | Total neutralizing power (TNP) | 101.8% |
| Pass No. 20 | 90% | Calcium (Ca) | 23.4% |
| Pass No. 60 | 60% | Magnesium (Mg) | 10.6% |
| Pass No. 100 | 50% | Moisture in fresh material, about | 5.0% |

He offers to spread this ground limestone on the field for $4 a ton, or will spread high-magnesium hydrated lime, TNP 170, for $12 a ton. Which should be the choice of a truck grower who is interested only in immediate effects and has been advised that his soil needs at least 2 tons calcium carbonate equivalent of quickly active lime to the acre to insure success with vegetables?

The analysis shows the ratio TNP/Mg to be 9.6, so this limestone may be evaluated as a dolomite. To plot the sieve analysis on the chart, temporary marks are made at 99% on the No. 8 sieve line, at 90% on the No. 20 line, at 60% on the No. 60 line, and at 50% on the No. 100 line. The points are seen to lie on a curve. Their general

[5]The activity of ground burned lime and hydrate is considered to be identical with total neutralizing power, irrespective of magnesium content and time. The chart is intended for the evaluation of raw limestone only.

position shows that this sample is a little finer than the average agricultural ground limestone. Laying a transparent straightedge on the chart and comparing the positions of the four points for this sample with the corresponding points representing the average for the grade Agricultural Ground Limestone, as printed on the chart, the position of the fineness line for this sample is decided.[6]

The fineness line for this sample, located as described, is noted to intersect the Three Months Dolomite efficiency line printed on the chart at 47%, which is our value *d*. Then, for $d \times$ TNP/100, we have $47 \times 1.018 = 48\%$ calcium carbonate equivalent (CCE) active lime supplied in 3 months. The correction for 5% moisture in the fresh material, multiplication by $(100 - 5)/100 = 0.95$, reduces the activity to 46% CCE. Therefore, to supply 2 tons CCE of lime active within 3 months, considered to be the minimum necessary, there must be applied $2/0.46 = 4.35$ tons of the ground limestone, costing \$17.40. The same amount of active lime will be supplied by $2/1.70 = 1.18$ tons of the hydrate, costing \$14.15. The hydrate offers the better value when immediate effect is the sole consideration.

But suppose that the grower anticipates the acute need for lime by applying it the previous year to the field he intends to put in vegetables. The fineness line then intersects the One Year Dolomite efficiency line at 72%, our new value for *d*. Applying the same corrections for composition, this becomes 70% CCE active lime supplied in 1 year. Two tons CCE of lime active the first year will be supplied by $2/0.70 = 2.85$ tons of the limestone, costing \$11.40. The cost of the required amount of active lime in hydrate will be the same as before, \$14.15, so the limestone offers the better value if applied a year in advance.

*Example 2.*—For the 1941 season, a dealer in Ohio offered liming materials delivered at nearby farms, with guarantees and prices per ton as noted below:

A. Coarse high-calcium limestone meal, 22% passes No. 100, TNP 95%, at \$2.50 a ton.

B. Fine high-calcium limestone meal, 33% passes No. 100, TNP 95%, at \$2.80 a ton.

C. High-calcium agricultural ground limestone, 55% passes No. 100, TNP 95%, at \$3.50 a ton.

D. Pulverized kiln-dried dolomitic limestone in bags, 78% passes No. 100, TNP 107%, at \$6.25 a ton.

E. High-calcium hydrated lime in bags, TNP 135%, at \$10.50 a ton.

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[6]In this decision, most weight is attached to the pass No. 100 and pass No. 60 points, somewhat less to the pass No. 20 point, and little to the pass No. 8 point, since the latter represents so small a percentage not passing. Of the three significant points, that for the No. 20 sieve represents only 10% of the total material, so is given less weight. Of the two highly significant points remaining, since both represent fine material, the slope of the nearest average fineness line has considerable influence in deciding the best position for the fineness line of this sample. The fineness line decided upon will be duplicated if a straightedge is laid at 97.5 on the No. 8 line at the left and at 28 on the No. 200 line at the right edge of the chart.

F. High-magnesium hydrated lime in bags, TNP 175%, at $11.50 a ton.

What are the costs of active lime in these products, on 1 and 4 year bases?

This example is intended to illustrate the simplest possible use of the chart in solving a practical problem with only a minimum of data. Values estimated for the ground limestone products with the aid of the chart and for the hydrates by calculation only are shown in the tabular arrangement following:

| Material | Estimated efficiencies and costs per ton CCE of active lime | | | |
|---|---|---|---|---|
| | In first year | | In first four years | |
| | Efficiency | Cost | Efficiency | Cost |
| A | 55 | $5.14 | 63 | $4.50 |
| B | 67 | 4.72 | 74 | 4.28 |
| C | 84 | 4.73 | 89 | 4.45 |
| D | 92 | 6.34 | 97 | 6.02 |
| E | 135* | 7.77 | 135* | 7.77 |
| F | 175* | 6.57 | 175* | 6.57 |

*Activity as percentage calcium carbonate equivalent.

For the high-calcium meals and ground limestone, all with the same guaranteed total neutralizing power, 95% calcium carbonate equivalent, efficiencies were estimated by laying the straightedge on the chart to pass through the points on the No. 100 sieve line corresponding to the guarantees, in each instance adjusting the slope to be consistent with those of the adjacent average fineness lines and reading values at the intersections with the One and Four Years Calcite efficiency lines. For the pulverized dolomitic limestone, values were read at the intersection of its fineness line with the corresponding dolomite efficiency lines. The total neutralizing power guarantees were taken into account, likewise probable moisture contents, in calculating costs per ton calcium carbonate equivalent of lime active in the times considered. There were no guarantees for moisture contents, but it was assumed that the bulk materials contained 7% moisture, the optimum for handling with an endgate spreader, and that the bagged materials were dry. For example, material C has TNP 95 and sells for $3.50 a ton. It is assumed to contain 7% moisture. The One Year Calcite efficiency was read 84%. The calculation is $\frac{\$3.50}{0.84 \times 0.95 \times 0.93} = \$4.73$, cost per ton CCE lime active in 1 year. For the hydrated limes, with activities not considered to increase with time and dependent upon TNP only, the chart is not used. For example, the calculation with the last is $\frac{\$11.50}{1.75} = \$6.57$, cost per ton CCE lime active in any time.

## COMPARISON WITH EVALUATION BY OTHERS

Some simpler methods for agricultural limestone evaluation with sieve analysis data have been proposed. DeTurk (4) has published the "Illinois Limestone Score Card", a set of factors to be used with sieve analysis data and the products summed for a comparative value on the principle of our arithmetical method. No consideration is given differences in chemical composition or time. A study of values so indicated for average grades of limestone has revealed that this method as originally described furnishes comparative values corresponding closely to ours when there is assumed a very high value for $a$, according to our experimental data excessive in relation to economic time periods and rates of application. Doctor DeTurk has stated in a personal communication that in developing this method he had in mind only long time values, about 12 to 15 years. The tendency will therefore be to overvalue coarse grades over shorter times.[7]

Coleman and Klemme (3) have recently published a method in which the percentage of the material passing 12-mesh (No. 14) is taken as an index of comparative value. A regularity in size composition is thus assumed similar to that on which our chart is based. In fact, the data for average limestone grades sold in Missouri plot as practically straight lines of normal slope on the chart, only those for the finest grade showing much departure from a linear relation. In a personal communication, these authors state that their conclusions are based on a study of the size composition of agricultural limestones on the Missouri market and some data for rates of activity of limestone size classes published by the Pennsylvania station (6). The latter were based on experiments continued for two years, with no attempt to evaluate the time factor further. Any conclusions therefrom may be expected to be more applicable to short times than to long times of activity in the soil. A comparison of the values indicated for representative grades by the Missouri method and by our method shows good agreement when there is assumed a small value of $a$. In contrast with the Illinois method, the tendency will be to undervalue coarse materials over longer times. With both the Illinois and Missouri methods of evaluation, differences in chemical composition as well as the time factor are neglected.

## SUMMARY

A chart for graphic evaluation of agricultural limestone is described and figured, with examples of use in solving practical problems. It may be read with practical accuracy if sufficient fundamental data

[7]In a recent publication from the Illinois station (Ann. Rpt., 51:35–37, 1942), the limestone score card factors are revised. Although the value assigned to the very coarsest particles, 4- to 6-mesh, is lowered to a point consistent with our evaluation of the 16-year efficiency of that size class, the values assigned to other coarse size classes are not, and all material passing 28-mesh (No. 30) is assumed to be of equal value, in contrast with the original assumption that the pass 100-mesh (No. 100) material shows maximum activity. The new plan for evaluation therefore favors coarse materials even more than does the old one.

are available, or for rough indications from very limited data, and in either case with facility after its use is understood. This is the first method to be published which takes into consideration all the variables, time, chemical and size composition, influencing the value of limestone as a soil neutralizer and source of active lime, and based on experiments simulating practical field conditions.

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# INHERITANCE OF GREEN AND BROWN LINT IN UPLAND COTTON[1]

T. R. RICHMOND[2]

THE normal color of the lint of cultivated upland cotton, *Gossypium hirsutum* L., is white or creamy white. Upland cottons with several shades of brown lint and one or possibly two shades of green lint have been reported. These manifestations of lint color could be the results of recent mutations from the normal white, but as the cotton of antiquity is usually described as having colored fibers, the various colors in the lint may have been carried as mixtures in cultivated stocks for many years. This paper gives the results of genetic studies with three types of brown lint and a green lint cotton.

## LITERATURE

According to Watt (11),[3] "All truly wild species have a red coloured woolly coating to the seed, which may or may not be referable to two layers, an inner, or fuzz, and an outer, or floss." He states also that, "the presence of a white fleece may accordingly be regarded as a condition brought about by cultivation."

Ware (8, 10) and Brown (2) have shown that the $F_1$ generation of a cross of Nankeen brown lint $\times$ white lint was intermediate in color and the $F_2$ segregated in ratio of 1 brown: 2 intermediate: 1 white. Ware (9) has reported on four strains of cotton carrying rust, dingy brown, yellowish brown, and green lint, respectively. Each type when crossed with its white allelomorph was "an intergrade between that of the respective colored parents and the white parent," and in the $F_2$ generation the crosses segregated into three classes in the ratio of 1 colored parental type: 2 intermediate: 1 white parental type.

## MATERIALS AND METHODS

One inbred line of upland cotton with green lint and three inbred lines of brown lint cotton were used in this study. The records of the parentage of the green lint strain are not clear, but it is presumed to be a selection from an old stock known as Texas Green Lint. The brown lint strains, Nankeen, Texas Rust, and Higginbotham, were obtained from stocks at the Texas Agricultural Experiment Station. Nankeen lint is dark brown and when in homozygous condition gives a distinct contrast to the light brown or buff color of Texas Rust. The color of the lint of Higginbotham is only slightly lighter than that of Texas Rust, and until recently both were thought to be expressions of the same gene. Most of the material reported in this paper involves crosses of Texas Green Lint, Nankeen, and Texas Rust. Hutchinson and Silow (5) have given symbols for several genes which condition color in cotton lint, but as the stocks used in this study have not been checked with their types, symbols will not be assigned to our types until

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[3]Numbers in parenthesis refer to "Literature Cited", p. 974.

this has been done. Our types will be referred to in the tables and elsewhere in the paper, when convenient, by an abbreviation of the names as follows:

| | |
|---|---|
| Types with green lint: | |
| Texas Green Lint | TGL |
| Types with brown lint: | |
| Nankeen | Nan |
| Texas Rust | TR |
| Higginbotham | Hig |
| Types with white lint: | |
| White Lint | W |

The $X^2$ method for the determination of the goodness of fit, as given by Fisher (4), was used in testing the monohybrid ratios. The dihybrid ratios were tested by Mather's (7) method of analysis of $X^2$ by orthogonal function.

## EXPERIMENTAL RESULTS

### GENETIC ANALYSIS

Segregating generations of crosses in the six possible combinations between Texas Green Lint, Nankeen, Texas Rust, and normal white lint lines were classified for lint color. The results are given in Table 1. With the exception of the TGL × Nan cross (Table 1, No. 7), progenies of each $F_1$ backcrossed to normal white were available for classification (Table 1, Nos. 2, 4, 6, 9, and 11). Texas Rust and Higginbotham were considered for several years to be the same genotype, but, as will be shown, the results of one backcross progeny indicates a difference in the genotype for lint color (Table 1, No. 13).

Crosses of TGL, Nan, and TR with white lint invariably have shown mono-hybrid inheritance with incomplete dominance (Table 1, Nos. 1, 3, and 5). The goodness of fit of the observed to the theoretical numbers when the data for each class of each family are combined is given as *deviation* $\chi^2$ and the agreement among families in the type of segregation is given in terms of *heterogeneity* $\chi^2$. In these crosses the respective probability values show no significant deviation from theoretical expectations. These findings are in agreement with those of Harland (6), Ware (9), and others who have studied crosses of these or similar stocks.

The segregating progenies of crosses of TGL×Nan and TGL×TR were separated into four classes designated as brown-green, brown, green, and white (Table 1, Nos. 7 and 8). A two-factor type of segregation was clearly indicated. Both $F_2$ progenies fit a 9:3:3:1 ratio and the backcross progeny of (TGL × TR) × W fit a 1:1:1:1 ratio (Table 1, No. 9). The families within each cross were in agreement with respect to their respective types of segregation as measured by the heterogeneity $\chi^2$. The $\chi^2$ for joint segregation (linkage) was .24 ($P = .50 - .70$) in the TGL×Nan $F_2$ segregation and .71 ($P = .30 - .50$) in the TGL × TR $F_2$ segregation. Both values are nonsignificant.

Four $F_2$ families of the cross Nan × TR were grown (Table 1, No. 10). Two classes of lint color were evident; one, a dark to intermediate brown class, and the other, a light brown class resembling

TABLE 1.—*Segregation for lint color in crosses involving Texas Green Lint, Nankeen, Texas Rust, Higginbotham, and normal white lint.*

| Number | Cross | Generation | Number of families | Total population | Segregation | $X^2$ for | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Deviation | P | Heterogeneity | P |
| 1 | TGL × W | $F_2$ | 8 | 789 | 1:2:1 | 3.170 | 0.20–0.30 | 12.530 | 0.50–0.70 |
| 2 | (TGL × W) × W | Backcross | 3 | 276 | 1:1 | 1.754 | 0.10–0.20 | 2.976 | 0.20–0.30 |
| 3 | Nan × W | $F_2$ | 5 | 1,333 | 1:2:1 | 4.597 | 0.10–0.20 | 7.103 | 0.50–0.70 |
| 4 | (Nan × W) × W | Backcross | 4 | 378 | 1:1 | 0.021 | 0.80–0.90 | 1.906 | 0.50–0.70 |
| 5 | TR × W | $F_2$ | 6 | 433 | 1:2:1 | 0.670 | 0.50–0.90 | 9.890 | 0.30–0.50 |
| 6 | (TR × W) × W | Backcross | 3 | 132 | 1:1 | 1.480 | 0.20–0.30 | 1.71 | 0.30–0.50 |
| 7 | TGL × Nan | $F_2$ | 2 | 340 | 9:3:3:1 | 3.049 | 0.30–0.50 | 7.103 | 0.05–0.10 |
| 8 | TGL × TR | $F_2$ | 3 | 213 | 9:3:3:1 | 0.942 | 0.80–0.90 | 2.135 | 0.90–0.95 |
| 9 | (TGL × TR) × W | Backcross | 2 | 57 | 1:1:1:1 | 2.720 | 0.30–0.50 | 6.020 | 0.10–0.20 |
| 10 | Nan × TR | $F_2$ | 4 | 183 | 3:1 | 0.410 | 0.50–0.70 | 22.634 | $<.01$ |
| 11 | (Nan × TR) × W | Backcross | 1 | 41 | 1:1 | 0.025 | 0.80–0.90 | —— | —— |
| 12 | (Nan × Hig) × W | Backcross | 1 | 67 | 3:1 | 1.438 | 0.20–0.30 | —— | —— |
| 13 | (TR × Hig) × W | Backcross | 1 | 69 | 3:1 | 0.043 | 0.80–0.90 | —— | —— |

TR in color. Although the darker class contained individuals ranging in color from a type darker than the Nan to a type resembling intermediate Nan, it was not possible to separate them into distinct sub-classes. Therefore, they were all thrown into one class which contained approximately three-fourths of the entire population. The $\chi^2$ for goodness of fit to a 3:1 ratio was .41 (P = .50 – .70). The heterogeneity $\chi^2$ of 22.63 (P = less than .01) indicates that the families did not segregate in a similar manner. Small numbers in some families may have been partly responsible. A backcross progeny (Table 1, No. 11) gave 20 dark brown and 21 light brown segregates. It is significant that no white lint segregates appeared in either the $F_2$ or backcross populations.

Progenies of Nan × Hig $F_1$ backcrossed to W and TR × Hig $F_1$ backcrossed to W were grown for another study, but when normal white lint segregates were observed they were classified for lint color (Table 1, Nos. 12 and 13). All brown lint segregates were placed in one class. The observed segregations of both crosses did not differ significantly from a ratio of 3 brown: 1 white.

The results obtained lead to the following conclusions: (a) The lint colors, Texas Green Lint (TGL), Nankeen (Nan), and Texas Rust (TR), each are conditioned by a single gene which is incompletely dominant in crosses with white lint. (b) The gene for Texas Green Lint is independent of those for Nankeen and Texas Rust. (c) The genes for Nankeen and Texas Rust are alleles. (d) Higginbotham brown lint, though inadequately tested, appears to be conditioned by a single gene which is different from, and probably independent of, the genes for Nankeen and Texas Rust.

## COLOR ANALYSIS

The 102 individual plant samples from one $F_2$ family of the Texas Green Lint × Texas Rust cross were studied on a color analyzer in an effort to obtain numerical values for the different color components. Once the samples from the $F_2$ were separated into four main classes, it was evident that each class, except white, could be separated further, thus facilitating a more critical color analysis. Since the monohybrid experiments had demonstrated incomplete dominance for both the brown lint gene and the green lint gene, and as the dihybrid experiments had shown these genes to be independent, it was expected that each of the nine possible genotypes could be recognized phenotypically. Regrouping of the main classes was attempted on this basis, the separation being made according to the appearance of the samples to the unaided eye. In no case did the numbers obtained for the various classes differ significantly from a 1:2:2:4:1:2:1:2:1 ratio, the $\chi^2$ being .379 (P more than .90). While every effort was made to eliminate bias in breaking down the main classes into their less sharply defined sub-classes, it would appear from the high probability value obtained that some control was exercised.

Each sample was carded on a pair of old-fashioned hand cards. This operation mixed the fibers thoroughly and the resulting flattened

bat was adaptable to analysis under the Bausch and Lomb H. S. B. color analyzer. This instrument employs the principle of a visual comparison of the material to Munsell discs of known color. The method of analysis recommended by the Bausch and Lomb Optical Company (1) was followed in this study. The terminology used is that adopted by the Colorimetry Committee of the Optical Society of America (3). According to this system the components of color are, hue saturation and brilliance.

When the color of the sample and the color of the discs have been matched through the manipulation of the discs, the color of the sample may be expressed numerically. This system does not provide a method for the expression of color as one figure; instead, numbers are arranged to indicate differences according to the three color attributes. For convenience, the three figures are written as a whole number and a common fraction, the first denoting hue, the figure above the line brilliance, and the figure below the line saturation.

In this paper no attempt has been made to give the color components for each sample analyzed, but Table 2 gives the average and extreme components of color for each of the nine classes. Occasionally, a single individual fell outside the limits of probability set by the standard deviation, with respect to one of the components of color, but of the samples of lint from 102 plants examined, only one fell outside the limits of probability with respect to two components of color. In no case was there an individual out of bounds for all three color components.

The diagram[4] shown as Fig. 1 was plotted from the average color specifications given in Table 2. A definite grouping of the classes predominating in green about the green type will be noted. The white class is highest on the brilliance scale, with the intermediate brown and intermediate green lying between this class and their respective parental types. The intermediate brown and white classes have practically the same hue and both are closer to brown than to green in this respect. The intermediate green class is nearly the same as the intermediate brown in brilliance, and it lies fairly close to the parental green type in hue. The intermediate brown-intermediate green class falls between the parental types and the intermediate monohybrid types in brilliance, and while falling between the latter types in hue, it closely approaches the intermediate green in this respect. The brown-green class lies close to brown in both brilliance and hue. If the brown lint and green lint genes were equal in their expression of hue the brown-green class should have fallen on a general line between brown and green. The same is true of certain of the other classes discussed. From these data it would appear that when the brown lint gene is in the heterozygous condition, the green lint gene present either in the homozygous or heterozygous condition is the largest contributor to hue. However, when the gene for brown lint is present in the homozygous condition, the

[4]Figure suggested by Miss Dorothy Nickerson, Color Technologist, Food Distribution Administration (formerly Agricultural Marketing Service), U. S. Dept. of Agriculture.

TABLE 2.—*Average and extreme color specifications in terms of hue, saturation, and brilliance of the nine $F_2$ classes of a Texas Green Lint × Texas Rust cross.*

| Class | Average color specifications | Extremes of color specifications |
|---|---|---|
| Brown-Green | 17.58YR $\frac{5.36}{3.86}$ | 16.57YR–17.89YR $\frac{5.11-5.85}{3.59-4.08}$ |
| Brown—Int. Green | 16.29YR $\frac{5.72}{3.94}$ | 15.95YR–16.66YR $\frac{5.50-5.97}{3.76-4.08}$ |
| Int. Brown-Green | 28.58Y $\frac{6.11}{3.65}$ | 28.20Y–28.99Y $\frac{5.94-6.23}{3.40-4.06}$ |
| Int. Brown-Int. Green | 28.47Y $\frac{6.80}{3.57}$ | 27.71Y–29.60Y $\frac{6.21-7.27}{2.74-4.33}$ |
| Brown | 17.53YR $\frac{5.56}{4.38}$ | 16.19YR–18.21YR $\frac{5.45-5.64}{4.03-5.53}$ |
| Int. Brown | 20.89Y $\frac{7.08}{3.07}$ | 20.41Y–21.29Y $\frac{6.55-7.26}{2.68-3.71}$ |
| Green | 30.72GY $\frac{6.16}{3.42}$ | 29.95Y–31.37GY $\frac{6.09-6.24}{3.18-3.57}$ |
| Int. Green | 29.56Y $\frac{7.23}{3.50}$ | 28.92Y–30.44GY $\frac{6.81-7.73}{3.06-4.18}$ |
| White | 21.12Y $\frac{7.92}{1.74}$ | 20.88Y–21.50Y $\frac{7.67-8.04}{1.62-1.84}$ |

green lint gene, present either in the homozygous or heterozygous condition, appears to have no measurable effect on hue.

## FINENESS OF THE FIBERS

Interesting differences in the physical nature of brown and green lint are brought out by a study of the fineness of the fiber. Several season's experience in handling green lint cotton and segregates from crosses involving green lint developed the impression that the lint from homozygous green individuals was softer and silkier than either brown lint or white lint. It appeared that the fibers from pure green lint were actually finer or smaller in cross-sectional area than those from white or brown. Harland (6) and Ware (9) have reported that fine fibers seem to be completely linked with green lint.

Measurements of the fineness of the fiber, using the weight per unit length method, and the mean and upper quartile length were

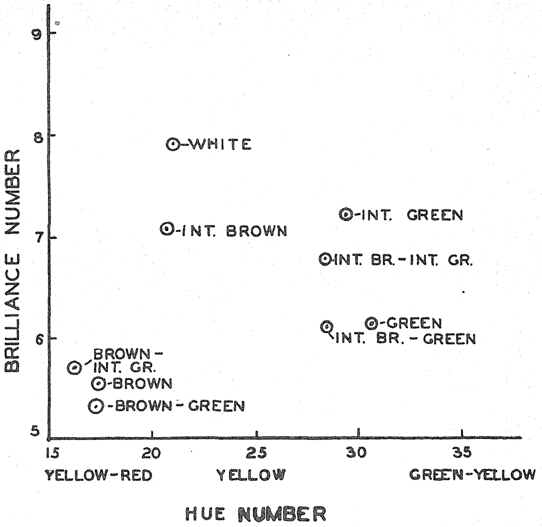


FIG. 1.—Diagram of average color specifications for each of nine $F_2$ classes of a Texas Green Lint × Texas Rust cross.

made on composite lint samples from each of the nine phenotypic classes of the $F_2$ generation of the TGL × TR cross in 1937.[5] As shown in Table 3, the homozygous classes, green, brown, white, and brown-green, weighed 3.1, 3.9, 4.6, and 2.9 micrograms per unit inch, respectively. Apparently the gene for green lint also conditions the fineness of the fiber or is completely linked with a gene with this effect, and as will be observed from its expression in various combinations, the degree of fineness is fixed within fairly well-defined limits. The brown lint gene has much the same function except that the degree of fineness falls between that of green and white. The homozygous green-brown class had the finest fibers and the homozygous white had the coarsest fibers of the nine classes on which fiber fineness determinations were made. The intermediate classes fall into place in accordance with the amount or degree of fineness con-

[5]The measurements of these fiber properties were made at the Cotton Fiber and Spinning Research Laboratory of the Food Distribution Administration (formerly Agricultural Marketing Service) in cooperation with the A. and M. College of Texas. Special acknowledgment is given to W. S. Smith in connection with these measurements.

tributed by the parents. These results suggest a case of Mendelian inheritance of a size character. Color and fineness are so closely associated as to leave little doubt that the expression of fiber fineness is an additional effect of the genes for green and brown lint, although fineness determinations on individual plants were not made, and a population sufficiently large to detect crossing over, if two closely linked genes were involved, was not grown.

TABLE 3.—*Fineness of fiber, upper quartile, and mean length of lint from composite samples from each of the nine phenotypic classes of the $F_2$ generation of a brown lint by green lint cross.*

| Class | Mean weight/ unit length inches, micro-grams* | Coefficient of variability | Length at 25% point, inches | Mean length, inches | Coefficient of variability |
|---|---|---|---|---|---|
| Brown-Green | 2.9 | 6.55 | 0.908 | 0.675 | 41.72 |
| Brown—Int. Green | 4.0 | 6.75 | 0.978 | 0.803 | 30.64 |
| Int. Brown-Green | 2.9 | 8.97 | 1.026 | 0.797 | 37.01 |
| Int. Brown-Int. Green | 4.2 | 8.57 | 1.084 | 0.887 | 31.12 |
| Brown | 3.9 | 4.87 | 0.983 | 0.778 | 35.73 |
| Int. Brown | 4.3 | 6.74 | 1.056 | 0.841 | 34.48 |
| Green | 3.1 | 6.45 | 0.989 | 0.799 | 33.17 |
| Int. Green | 4.0 | 9.50 | 1.050 | 0.874 | 28.83 |
| White | 4.6 | 9.35 | 1.050 | 0.864 | 29.98 |

*1 microgram = $10^{-3}$ milligrams.

## SUMMARY

1. The lint colors in Texas Green Lint, Nankeen (dark brown lint), Texas Rust (light brown lint), and Higginbotham (light brown or tan lint) cotton were studied.

2. Texas Green Lint, Nankeen, and Texas Rust each are conditioned by a single gene which is incompletely dominant in crosses with white lint. The gene for Texas Green Lint is independent of those for Nankeen and Texas Rust; and the genes for Nankeen and Texas Rust are alleles. Higginbotham brown lint appears to be genetically different from, and independent of, Nankeen and Texas Rust.

3. A numerical expression of color of each segregate of a Texas Green Lint × Texas Rust cross was obtained by colorimetric analysis.

4. The respective genes for green lint and brown lint appear to inhibit the development of the fiber with respect to weight per unit length.

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# TOP-ROOT RATIOS OF INBRED AND HYBRID MAIZE[1]

D. Boyd Shank[2]

TO PRODUCE maximum yields of grain, plants must have efficient root systems for obtaining sufficient minerals and water for optimum top growth. Furthermore, their roots should be of such a nature as to prevent lodging. Since roots vary in diameter and in surface per unit weight, root surface, especially absorbing surface, would be desirable as a criterion of root value. To date no practical procedure has been devised for obtaining root surfaces rapidly, leaving weight as the most usable measure available for experiments necessitating large numbers of determinations. However, root weight alone is not a good criterion of root value as two root systems of equal weight may have to support tops of unequal size. Therefore, in the following experiments, top-root ratios, which express the relative growth of tops to roots, were used. These ratios give a balance or pattern of plant growth which has received little attention in genetic studies.

It was the object of this investigation to determine what differences exist among the top-root ratios of fixed inbred lines of maize and to determine how these differences are inherited in hybrids.

## REVIEW OF LITERATURE

Schulze (8)[3] found the relationship of weight of tops to weight of roots to be 100:7.4, 100:9.0, 100:4.7, 100:9.2, 100:3.4 and 100:38.9, respectively, for mature plants of barley, oats, rye, wheat, peas, and beans.

Working with plants shortly after anthesis had set in, King (5) obtained values of 3.34:1, 2.23:1, 4.00:1 and 6.84:1 for barley, oats, clover and corn, in the order named.

Schneider (7), using 88 varieties of oats, found that among mature plants the ratio of weight of tops to weight of roots ranged from 100:28.2 to 100:10.6.

Boonstra (1), testing seven races of peas, found that the ratio of dry weight of shoot to dry weight of root varied from 8.27 to 16.76.

Weihing (12) placed a number of regional corn varieties into the three vegetative types of small, medium, and large. Top-root ratios based on dry weights of mature plants, when grown under comparable conditions, for the three types were 6.42, 4.90, and 3.47, respectively.

Harvey (3) discovered significantly different top-root ratios between inbred strains of maize.

Burkholder and McVeigh (2), working with corn inbreds and hybrids supplied with various levels of nitrogen, reported that the inbred $R_4$ had notably high shoot-root ratios at all nitrogen levels.

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[1]Part of a thesis submitted to the graduate faculty at the Iowa State College in partial fulfillment of the requirements for the degree of doctor of philosophy. Contribution from the Genetics Section, Iowa Agricultural Experiment Station, Ames, Iowa. Journal Paper J-1128. Project 250. Received for publication June 14, 1943.

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[3]Figures in parenthesis refer to "Literature Cited", p. 987.

Holbert, *et al.* (4) found root-top ratios of 0.62, 0.66, 0.83, and 0.85 for four inbred lines of maize harvested when slightly over 8 weeks of age.

Koehler, *et al.* (6), working with two pairs of self-fertilized corn strains, found that crossing of weak- and strong-rooted plants usually resulted in an $F_1$ generation with little lodging. However, one cross gave $F_1$ plants that were practically 100% lodged. They concluded that the inheritance of tendencies for strong and weak roots cannot be explained by a single genetic factor.

Spencer (10) found that top-root ratios for two single cross corn hybrids were approximately intermediate between those of their inbred parents up to the time of silking, at which time the hybrids equaled or exceeded the inbred with the larger ratio.

## MATERIALS AND METHODS

Twelve first cycle and seven second cycle yellow dent inbreds, one white flint inbred, and one yellow sweet inbred were used. (First cycle inbreds are selfs from varieties, while second cycle inbreds are recovered lines obtained by back-crossing $F_1$ hybrids one or two generations before inbreeding.) A brief description of the majority of the first cycle inbreds and of the reccurent parents of the second cycle inbreds may be found in Table 3, pages 504 to 519 of the 1936 Yearbook of the U. S. Dept. of Agriculture.

All but one of the strains were secured through the courtesy of E. W. Lindstrom. The single exception, LE23, was obtained from the Pioneer Hi-Bred Corn Company of Johnston, Iowa.

Plants for root studies were grown in the greenhouse for periods of from 4 to 6 weeks in the three mediums, aqueous solution, soil, and sand. The general method of handling each will be given separately.

For water cultures two different solutions were employed. These were modifications of the one used by Smith (9) and of the buffered solution Zinzadzé (13) recommended for constant pH. Basically they were made up as follows:

| Modified Smith's solution | | Buffered solution | |
|---|---|---|---|
| Salt | Grams per liter of solution | Salt | Grams per liter of solution |
| KCl | 0.288 | KCl | 0.286 |
| $MgSO_4.7H_2O$ | 0.432 | $MgSO_4.7H_2O$ | 0.500 |
| $Ca(NO_3)_2.4H_2O$ | 0.469* | $NH_4NO_3$ | 0.286 |
| $(NH_4)_2SO_4$ | 0.115 | $Ca_3(PO_4)_2$ | 0.500 |
| $KH_2PO_4$ | 0.066 | | |

*This solution contains 80 p.p.m. of nitrogen. In some of the earlier experiments a concentration of only 40 p.p.m. was used. These experiments will be designated.

Colloidal $Ca_3(PO_4)_2$ for the buffered solution was prepared by dissolving 13.69 grams of $K_3PO_4$ in 1 liter of warm water while 10.73 grams of anhydrous $CaCl_2$ were dissolved in a second liter of warm water. The two solutions were then mixed with vigorous stirring, giving a finely divided suspension of $Ca_3(PO_4)_2$ containing KCl in solution. This solution was used as made up at the rate of 100 ml per liter of nutrient solution.

Iron, in the form of ferric tartrate, was added as needed by the plants. The supply of micro-nutrients was furnished by impurities in the C.P. salts and in the tap water used for all cultures.

Solutions were changed every 5 to 14 days, depending on the time of year and

size of the plants. Tap water was added between solution changes as needed to replace that lost by transpiration and evaporation.

Methods of obtaining seedling plants and setting them up in water cultures were similar to those described by Harvey (3). In all tests, plants were grown in painted quart Mason jars which had been treated with formalin before using to reduce fungal growth. Two seedlings per jar constituted a unit.

For soil cultures, mixtures of 3 parts of compost to 1 part top soil and 1 part sand put through an 8-mesh seive and thoroughly mixed, were used. However, this ratio was often varied as the lots of compost and top soil differed widely in fertility.

The purpose of the sand cultures was to provide a medium for plant growth of slightly different structure than soil cultures and one that was low in plant food. Washed river sand was used as the growing medium. A reduced concentration of the modified Smith's solution was added every 3 or 4 days in order to maintain limited plant growth.

Seed of each line used was a composite of two or three ears. Before using, the kernels were treated with either "Merko" or "New Improved Semesan Jr." mercury dusts.

All experiments conducted were set up in a completely randomized block design and analyses of variance were calculated on the data according to the method outlined by Snedecor (11). Rerandomization within replications was effected at weekly intervals.

In harvesting, roots of sand and soil culture plants were first carefully washed over a screen, then soaked for 3 or 4 hours and rewashed.

Dry weights in grams were obtained on tops and roots after they had been oven dried to a constant moisture level. The top-root ratios reported are the quotients obtained by dividing the dry weight of the tops by the dry weight of the roots.

## EXPERIMENTAL RESULTS

### DIFFERENCES IN TOP-ROOT RATIOS OF INBRED LINES

Test 1 consisted of 10 inbreds grown from May 3 to May 31, 1939, on the three cultures outlined above. Inbreds used ranged from strong to weak rooted ones as observed under field conditions. Water culture plants were raised on the buffered solution. Eight replications were used, giving 240 units. A summary of the mean top-root ratios is presented in Table 1 and the analysis of variance in Table 2.

Of primary interest in these studies was the fact that wide differences existed between the mean top-root ratios of the different lines. Based on all three cultures, means ranged from 1.40 to 2.07, the values for the various lines being spread rather uniformly over this range. In the analysis of variance (Table 2), line variation is highly significant, showing that these differences between strains were real under the conditions of this test. Ratios exhibited by individual lines agreed rather closely with their lodging resistance as observed in the field. KR(Osf), Hy, and KR, lines which are resistant to lodging, exhibited low ratios, i.e., a large amount of roots in proportion to tops, while PR and $R_4$, which usually lodge, had high ratios. In general, the lines were consistent in that they occupied about the same relative rank on all three cultures.

TABLE 1.—*Mean top-root ratios of ten inbreds as calculated from dry weights, test 1.*

| Inbred | Culture | | | Mean |
|---|---|---|---|---|
| | Water | Soil | Sand | |
| KR (Osf) | 2.03 | 1.27 | 0.90 | 1.40 |
| Hy | 1.79 | 1.73 | 1.05 | 1.52 |
| KR | 2.19 | 1.76 | 1.03 | 1.66 |
| TR (Ldg) | 2.27 | 1.85 | 1.00 | 1.71 |
| Osf | 2.19 | 2.11 | 1.08 | 1.79 |
| Ldg (PR) | 2.54 | 1.93 | 1.02 | 1.83 |
| WCR | 2.19 | 2.18 | 1.34 | 1.90 |
| M14 | 2.12 | 2.22 | 1.40 | 1.91 |
| $R_4$ | 2.63 | 2.21 | 1.33 | 2.06 |
| PR | 2.62 | 2.24 | 1.34 | 2.07 |
| Mean | 2.26 | 1.95 | 1.15 | 1.79 |

TABLE 2.—*Analysis of variance based on top-root ratios, test 1.*

| Source of variation | Degrees of freedom | Mean square |
|---|---|---|
| Replications | 7 | 0.07 |
| Lines | 9 | 1.13** |
| Cultures | 2 | 26.08** |
| Lines × cultures | 18 | 0.24** |
| Error | 203 | 0.05 |
| Total | 239 | |

**P less than 0.01.

The cultures account for the bulk of the variance in the analysis. The smallest mean difference between any two cultures was 0.31, existing between water and soil cultures. The standard error for a culture mean difference was ±0.04, making this highly significant.

That all lines did not respond the same to the three cultures is shown by the significance of the interaction of lines × cultures.

Test 2 was conducted to determine if the general results of test 1 could be repeated, especially under the changed environmental conditions existing during a different season of the year and with a longer period of plant growth. Nine inbreds were grown from June 28 to August 11, 1939. LE23, Osf(KR), and Idt(Baw) replaced M14, WCR, Osf, and Ldg (PR) of test 1. Modified Smith's solution with a nitrogen concentration of 40 p.p.m. was used in place of the buffered solution for water cultures. Tables 3 and 4 present the mean top-root ratios and the analysis of variance, respectively.

As in test 1, lines, cultures, and the interaction of lines × cultures were highly significant. In general, ratios in test 2 were slightly higher than in test 1. The explanation for this difference may have been that the plants in the second experiment were older, since top-root ratios increase with age (1, 10).

The six lines common to both test 1 and test 2 occupied the order

TABLE 3.—*Mean top-root ratios of nine inbreds as calculated from dry weights, test 2.*

| Inbred | Culture | | | Mean |
|---|---|---|---|---|
| | Water | Soil | Sand | |
| Osf(KR) | 2.46 | 1.87 | 1.61 | 1.98 |
| KR(Osf) | 2.12 | 2.55 | 1.61 | 2.09 |
| KR | 2.55 | 2.38 | 2.09 | 2.34 |
| Hy | 2.55 | 2.23 | 2.31 | 2.36 |
| Idt(Baw) | 2.78 | 2.05 | 2.31 | 2.38 |
| LE23 | 3.15 | 2.53 | 1.97 | 2.55 |
| TR(Ldg) | 2.80 | 2.73 | 2.34 | 2.63 |
| $R_4$ | 3.07 | 2.64 | 2.19 | 2.64 |
| PR | 3.16 | 3.88 | 2.33 | 3.12 |
| Mean | 2.74 | 2.54 | 2.09 | 2.45 |

TABLE 4.—*Analysis of variance based on top-root ratios, test 2.*

| Source of variation | Degrees of freedom | Mean square |
|---|---|---|
| Replications | 5 | 0.45 |
| Lines | 8 | 2.03** |
| Cultures | 2 | 6.05** |
| Lines × cultures | 16 | 0.62** |
| Error | 130 | 0.17 |
| Total | 161 | |

**P less than 0.01.

of KR(Osf), Hy, KR, TR(Ldg), $R_4$, and PR in test 1 when arrayed from low to high ratios. In test 2 they were in the same sequence, except for KR and Hy, which were reversed. This tends to substantiate the ranking in test 1.

Top-root ratios of additional inbred lines were determined in test 3. The test was conducted in the same manner as test 2, except nitrogen was raised to 80 p.p.m. in the water cultures.

Ten inbreds were used which included eight new strains and two, KR and PR, which were included in tests 1 and 2. Since KR has a low and PR a high top-root ratio, they were included as checks for a comparative evaluation of the ranking of the strains between tests. The plants were grown from March 2 to April 15, 1940.

Mean top-root ratios appear in Table 5 and the analysis of variance in Table 6. As in tests 1 and 2, lines, cultures, and the interaction of lines × cultures were all highly significant. Two lines had lower means than KR and two higher than PR.

Throughout these tests individual inbred lines exhibited characteristic differences in the coarseness or diameter of primary and corresponding lateral roots. This was particularly true of water culture plants. Since the finer the roots, the greater surface a given weight will have, the root systems of test 3 were graded at harvest time on the basis of their relative coarseness into five numerical

TABLE 5.—*Mean top-root ratios of 10 inbreds as calculated from dry weights, test 3.*

| Inbred | Culture | | | Mean |
|---|---|---|---|---|
| | Water | Soil | Sand | |
| ITE | 2.06 | 1.24 | 1.11 | 1.47 |
| Ldg | 2.03 | 1.47 | 1.42 | 1.64 |
| KR | 1.99 | 1.72 | 1.24 | 1.65 |
| Ldg(K) | 2.28 | 2.07 | 1.41 | 1.92 |
| Bls | 2.86 | 1.79 | 1.28 | 1.98 |
| Mc | 2.85 | 1.98 | 1.45 | 2.09 |
| La(Bls) | 2.69 | 2.04 | 1.61 | 2.11 |
| PR | 3.06 | 2.11 | 1.63 | 2.27 |
| WF | 3.78 | 1.77 | 1.55 | 2.36 |
| GB134 | 4.17 | 2.50 | 2.10 | 2.92 |
| Mean | 2.78 | 1.87 | 1.48 | 2.04 |

TABLE 6.—*Analysis of variance based on top-root ratios, test 3.*

| Source of variation | Degrees of freedom | Mean square |
|---|---|---|
| Replications | 7 | 0.02 |
| Lines | 9 | 4.27** |
| Cultures | 2 | 35.40** |
| Lines × cultures | 18 | 0.88** |
| Error | 203 | 0.04 |
| Total | 239 | |

**P less than 0.01.

classes. Such wide differences in general root structure existed among the treatments, water culture producing coarse roots, soil culture intermediate to fine, and sand culture fine roots, that each culture was graded independently of the others. The mean grade for each line grown on each culture is presented in Table 7.

TABLE 7.—*Mean root grades of 10 inbreds, test 3.**

| Inbred | Culture | | |
|---|---|---|---|
| | Water | Soil | Sand |
| ITE | 1.8 | 3.3 | 2.6 |
| Ldg | 5.0 | 4.8 | 5.0 |
| KR | 4.9 | 3.0 | 3.5 |
| Ldg(K) | 4.8 | 2.9 | 3.6 |
| Bls | 3.3 | 1.3 | 2.6 |
| Mc | 3.1 | 3.8 | 3.9 |
| La(Bls) | 4.4 | 2.9 | 2.9 |
| PR | 2.3 | 1.6 | 1.6 |
| WF | 1.3 | 1.5 | 1.5 |
| GB134 | 1.0 | 2.3 | 1.0 |

*Grades are 1, fine primaries and fine laterals; 2, medium primaries and fine laterals; 3, medium primaries and medium laterals; 4, coarse primaries and medium laterals; and 5, coarse primaries and coarse laterals.

TABLE 3.—*Mean top-root ratios of nine inbreds as calculated from dry weights, test 2.*

| Inbred | Culture | | | Mean |
|---|---|---|---|---|
| | Water | Soil | Sand | |
| Osf(KR) | 2.46 | 1.87 | 1.61 | 1.98 |
| KR(Osf) | 2.12 | 2.55 | 1.61 | 2.09 |
| KR | 2.55 | 2.38 | 2.09 | 2.34 |
| Hy | 2.55 | 2.23 | 2.31 | 2.36 |
| Idt(Baw) | 2.78 | 2.05 | 2.31 | 2.38 |
| LE23 | 3.15 | 2.53 | 1.97 | 2.55 |
| TR(Ldg) | 2.80 | 2.73 | 2.34 | 2.63 |
| $R_4$ | 3.07 | 2.64 | 2.19 | 2.64 |
| PR | 3.16 | 3.88 | 2.33 | 3.12 |
| Mean | 2.74 | 2.54 | 2.09 | 2.45 |

TABLE 4.—*Analysis of variance based on top-root ratios, test 2.*

| Source of variation | Degrees of freedom | Mean square |
|---|---|---|
| Replications | 5 | 0.45 |
| Lines | 8 | 2.03** |
| Cultures | 2 | 6.05** |
| Lines × cultures | 16 | 0.62** |
| Error | 130 | 0.17 |
| Total | 161 | |

**P less than 0.01.

of KR(Osf), Hy, KR, TR(Ldg), $R_4$, and PR in test 1 when arrayed from low to high ratios. In test 2 they were in the same sequence, except for KR and Hy, which were reversed. This tends to substantiate the ranking in test 1.

Top-root ratios of additional inbred lines were determined in test 3. The test was conducted in the same manner as test 2, except nitrogen was raised to 80 p.p.m. in the water cultures.

Ten inbreds were used which included eight new strains and two, KR and PR, which were included in tests 1 and 2. Since KR has a low and PR a high top-root ratio, they were included as checks for a comparative evaluation of the ranking of the strains between tests. The plants were grown from March 2 to April 15, 1940.

Mean top-root ratios appear in Table 5 and the analysis of variance in Table 6. As in tests 1 and 2, lines, cultures, and the interaction of lines × cultures were all highly significant. Two lines had lower means than KR and two higher than PR.

Throughout these tests individual inbred lines exhibited characteristic differences in the coarseness or diameter of primary and corresponding lateral roots. This was particularly true of water culture plants. Since the finer the roots, the greater surface a given weight will have, the root systems of test 3 were graded at harvest time on the basis of their relative coarseness into five numerical

TABLE 5.—*Mean top-root ratios of 10 inbreds as calculated from dry weights, test 3.*

| Inbred | Culture | | | Mean |
|---|---|---|---|---|
| | Water | Soil | Sand | |
| ITE | 2.06 | 1.24 | 1.11 | 1.47 |
| Ldg | 2.03 | 1.47 | 1.42 | 1.64 |
| KR | 1.99 | 1.72 | 1.24 | 1.65 |
| Ldg(K) | 2.28 | 2.07 | 1.41 | 1.92 |
| Bls | 2.86 | 1.79 | 1.28 | 1.98 |
| Mc | 2.85 | 1.98 | 1.45 | 2.09 |
| La(Bls) | 2.69 | 2.04 | 1.61 | 2.11 |
| PR | 3.06 | 2.11 | 1.63 | 2.27 |
| WF | 3.78 | 1.77 | 1.55 | 2.36 |
| GB134 | 4.17 | 2.50 | 2.10 | 2.92 |
| Mean | 2.78 | 1.87 | 1.48 | 2.04 |

TABLE 6.—*Analysis of variance based on top-root ratios, test 3.*

| Source of variation | Degrees of freedom | Mean square |
|---|---|---|
| Replications | 7 | 0.02 |
| Lines | 9 | 4.27** |
| Cultures | 2 | 35.40** |
| Lines × cultures | 18 | 0.88** |
| Error | 203 | 0.04 |
| Total | 239 | |

**P less than 0.01.

classes. Such wide differences in general root structure existed among the treatments, water culture producing coarse roots, soil culture intermediate to fine, and sand culture fine roots, that each culture was graded independently of the others. The mean grade for each line grown on each culture is presented in Table 7.

TABLE 7.—*Mean root grades of 10 inbreds, test 3.**

| Inbred | Culture | | |
|---|---|---|---|
| | Water | Soil | Sand |
| ITE | 1.8 | 3.3 | 2.6 |
| Ldg | 5.0 | 4.8 | 5.0 |
| KR | 4.9 | 3.0 | 3.5 |
| Ldg(K) | 4.8 | 2.9 | 3.6 |
| Bls | 3.3 | 1.3 | 2.6 |
| Mc | 3.1 | 3.8 | 3.9 |
| La(Bls) | 4.4 | 2.9 | 2.9 |
| PR | 2.3 | 1.6 | 1.6 |
| WF | 1.3 | 1.5 | 1.5 |
| GB134 | 1.0 | 2.3 | 1.0 |

*Grades are 1, fine primaries and fine laterals; 2, medium primaries and fine laterals; 3, medium primaries and medium laterals; 4, coarse primaries and medium laterals; and 5, coarse primaries and coarse laterals.

TABLE 3.—*Mean top-root ratios of nine inbreds as calculated from dry weights, test 2.*

| Inbred | Culture | | | Mean |
|---|---|---|---|---|
| | Water | Soil | Sand | |
| Osf(KR) | 2.46 | 1.87 | 1.61 | 1.98 |
| KR(Osf) | 2.12 | 2.55 | 1.61 | 2.09 |
| KR | 2.55 | 2.38 | 2.09 | 2.34 |
| Hy | 2.55 | 2.23 | 2.31 | 2.36 |
| Idt(Baw) | 2.78 | 2.05 | 2.31 | 2.38 |
| LE23 | 3.15 | 2.53 | 1.97 | 2.55 |
| TR(Ldg) | 2.80 | 2.73 | 2.34 | 2.63 |
| $R_4$ | 3.07 | 2.64 | 2.19 | 2.64 |
| PR | 3.16 | 3.88 | 2.33 | 3.12 |
| Mean | 2.74 | 2.54 | 2.09 | 2.45 |

TABLE 4.—*Analysis of variance based on top-root ratios, test 2.*

| Source of variation | Degrees of freedom | Mean square |
|---|---|---|
| Replications | 5 | 0.45 |
| Lines | 8 | 2.03** |
| Cultures | 2 | 6.05** |
| Lines × cultures | 16 | 0.62** |
| Error | 130 | 0.17 |
| Total | 161 | |

**P less than 0.01.

of KR(Osf), Hy, KR, TR(Ldg), $R_4$, and PR in test 1 when arrayed from low to high ratios. In test 2 they were in the same sequence, except for KR and Hy, which were reversed. This tends to substantiate the ranking in test 1.

Top-root ratios of additional inbred lines were determined in test 3. The test was conducted in the same manner as test 2, except nitrogen was raised to 80 p.p.m. in the water cultures.

Ten inbreds were used which included eight new strains and two, KR and PR, which were included in tests 1 and 2. Since KR has a low and PR a high top-root ratio, they were included as checks for a comparative evaluation of the ranking of the strains between tests. The plants were grown from March 2 to April 15, 1940.

Mean top-root ratios appear in Table 5 and the analysis of variance in Table 6. As in tests 1 and 2, lines, cultures, and the interaction of lines × cultures were all highly significant. Two lines had lower means than KR and two higher than PR.

Throughout these tests individual inbred lines exhibited characteristic differences in the coarseness or diameter of primary and corresponding lateral roots. This was particularly true of water culture plants. Since the finer the roots, the greater surface a given weight will have, the root systems of test 3 were graded at harvest time on the basis of their relative coarseness into five numerical

TABLE 5.—*Mean top-root ratios of 10 inbreds as calculated from dry weights, test 3.*

| Inbred | Culture | | | Mean |
|---|---|---|---|---|
| | Water | Soil | Sand | |
| ITE | 2.06 | 1.24 | 1.11 | 1.47 |
| Ldg | 2.03 | 1.47 | 1.42 | 1.64 |
| KR | 1.99 | 1.72 | 1.24 | 1.65 |
| Ldg(K) | 2.28 | 2.07 | 1.41 | 1.92 |
| Bls | 2.86 | 1.79 | 1.28 | 1.98 |
| Mc | 2.85 | 1.98 | 1.45 | 2.09 |
| La(Bls) | 2.69 | 2.04 | 1.61 | 2.11 |
| PR | 3.06 | 2.11 | 1.63 | 2.27 |
| WF | 3.78 | 1.77 | 1.55 | 2.36 |
| GB134 | 4.17 | 2.50 | 2.10 | 2.92 |
| Mean | 2.78 | 1.87 | 1.48 | 2.04 |

TABLE 6.—*Analysis of variance based on top-root ratios, test 3.*

| Source of variation | Degrees of freedom | Mean square |
|---|---|---|
| Replications | 7 | 0.02 |
| Lines | 9 | 4.27** |
| Cultures | 2 | 35.40** |
| Lines × cultures | 18 | 0.88** |
| Error | 203 | 0.04 |
| Total | 239 | |

**P less than 0.01.

classes. Such wide differences in general root structure existed among the treatments, water culture producing coarse roots, soil culture intermediate to fine, and sand culture fine roots, that each culture was graded independently of the others. The mean grade for each line grown on each culture is presented in Table 7.

TABLE 7.—*Mean root grades of 10 inbreds, test 3.**

| Inbred | Culture | | |
|---|---|---|---|
| | Water | Soil | Sand |
| ITE | 1.8 | 3.3 | 2.6 |
| Ldg | 5.0 | 4.8 | 5.0 |
| KR | 4.9 | 3.0 | 3.5 |
| Ldg(K) | 4.8 | 2.9 | 3.6 |
| Bls | 3.3 | 1.3 | 2.6 |
| Mc | 3.1 | 3.8 | 3.9 |
| La(Bls) | 4.4 | 2.9 | 2.9 |
| PR | 2.3 | 1.6 | 1.6 |
| WF | 1.3 | 1.5 | 1.5 |
| GB134 | 1.0 | 2.3 | 1.0 |

*Grades are 1, fine primaries and fine laterals; 2, medium primaries and fine laterals; 3, medium primaries and medium laterals; 4, coarse primaries and medium laterals; and 5, coarse primaries and coarse laterals.

Individual lines were not consistent in their relative ranking between cultures. This may have been due to actual differences as caused by culture or to inaccuracies of classification. Under the conditions of this experiment, GB134, WF, and PR were relatively fine rooted, while Ldg, KR, and Ldg (K) were consistently coarse rooted.

## INHERITANCE OF TOP-ROOT RATIOS IN $F_1$ HYBRIDS

Two tests were conducted using inbreds which had exhibited wide ratio differences (in tests 1, 2, or 3) and single crosses between them. The experiments were handled in the same manner as were those for the inbreds.

Test 4 contained two pairs of inbreds, each pair consisting of two lines with widely differing top-root ratios, and reciprocal hybrids between lines within each pair. Eight replications were grown from June 20 to August 2, 1939. Smith's solution, containing 40 p.p.m. of nitrogen, was used for the water cultures. Mean top-root ratios are given in Table 8 and their analysis of variance in Table 9.

TABLE 8.—*Mean top-root ratios of inbreds and hybrids as calculated from dry weights, test 4.*

| Line | Culture | | | Mean |
|---|---|---|---|---|
| | Water | Soil | Sand | |
| PR | 3.18 | 3.61 | 2.72 | 3.17 |
| PR × Hy | 2.21 | 2.09 | 1.83 | 2.05 |
| Hy × PR | 2.17 | 2.24 | 1.71 | 2.04 |
| Hy | 2.30 | 2.63 | 2.03 | 2.32 |
| $R_4$ | 2.78 | 2.58 | 2.28 | 2.55 |
| $R_4$ × KR | 2.68 | 2.25 | 1.98 | 2.30 |
| KR × $R_4$ | 2.79 | 2.11 | 1.86 | 2.25 |
| KR | 2.55 | 2.44 | 1.77 | 2.25 |
| Mean | 2.58 | 2.49 | 2.02 | 2.37 |

TABLE 9.—*Analysis of variance based on top-root ratios, test 4.*

| Source of variation | Degrees of freedom | Mean square |
|---|---|---|
| Replications | 7 | 0.46 |
| Lines | 7 | 3.14** |
| Cultures | 2 | 5.81** |
| Lines × cultures | 14 | 0.32** |
| Error | 160* | 0.11 |
| Total | 190 | |

*One degree of freedom subtracted for a datum supplied by missing plot technic.
**P less than 0.01.

Mean ratios for the $F_1$ hybrids were either the same or very nearly the same as those of their lower ratio parent. Reciprocal hybrids did not differ in their mean top-root ratios.

Mean ratio differences between $F_1$ hybrids and their high ratio parents and between hybrids and their low ratio parents appear in Table 10. The total mean difference between the high ratio parents and the hybrids, based on all three cultures, was highly significant ($+2.79 \pm 0.24$), while that between the low ratio parents and the hybrids was significant only at the 5% level ($+0.61 \pm 0.24$). Since hybrid ratios were always subtracted from those of their parents to obtain the differences in Table 10, the positive values indicate that in this test hybrid ratios were actually slightly lower than were those of their low ratio parents.

TABLE 10.—*Mean differences in top-root ratios between hybrids and their high ratio parents and between hybrids and their low ratio parents, test 4.*

| Hybrid | Culture | | | Mean |
|---|---|---|---|---|
| | Water | Soil | Sand | |
| **High Ratio Parent Minus Hybrid** | | | | |
| PR × Hy | +0.97 | +1.52 | +0.89 | +1.13 |
| Hy × PR | +1.01 | +1.37 | +1.01 | +1.13 |
| $R_4$ × KR | +0.10 | +0.33 | +0.30 | +0.24 |
| KR × $R_4$ | −0.01 | +0.47 | +0.42 | +0.29 |
| Sum | +2.07 | +3.69 | +2.62 | +2.79 |
| S. E. of sum | ±0.41 | ±0.41 | ±0.41 | ±0.24 |
| **Low Ratio Parent Minus Hybrid** | | | | |
| PR × Hy | +0.09 | +0.54 | +0.20 | +0.28 |
| Hy × PR | +0.13 | +0.39 | +0.32 | +0.28 |
| $R_4$ × KR | −0.13 | +0.19 | −0.21 | −0.05 |
| KR × $R_4$ | −0.24 | +0.33 | −0.09 | +0.00 |
| Sum | −0.15 | +1.45 | +0.22 | +0.61 |
| S. E. of sum | ±0.41 | ±0.41 | ±0.41 | ±0.24 |

Mean differences between the hybrids and their high ratio parents were highly significant for each culture. When hybrid ratios were compared with those of their low ratio parents for each culture, only the value for soil ($+1.45 \pm 0.41$) attained significance. By comparing this value with those for water cultures and sand, i.e., $+1.45 - (-0.15 + 0.22)/2$, a value of $+1.41 \pm 0.51$ is obtained. The corresponding comparison involving the differences between the means of the hybrids and their high ratio parents gives a value of $+1.35 \pm 0.51$. These two comparisons are both highly significant, indicating that significance of the interaction of lines × cultures in the analysis of variance was partially caused by the failure of inbreds and hybrids to behave relatively the same when grown on soil as when grown on sand and water cultures. The cause of such a differential reaction is not known. Other interaction components tested proved to be nonsignificant.

Test 5, containing five inbreds and five $F_1$ hybrids, was grown from April 2 to May 11, 1940. Nitrogen in the water cultures was

maintained at 100 p.p.m. Mean top-root ratios are given in Table 11 and the statistical analysis in Table 12.

TABLE 11.—*Mean top-root ratios of inbreds and hybrids as calculated from dry weights, test 5.*

| Line | Culture | | | Mean |
|---|---|---|---|---|
| | Water | Soil | Sand | |
| KR(Osf) | 1.54 | 1.33 | 0.88 | 1.25 |
| KR(Osf) × Hy | 1.39 | 1.30 | 0.95 | 1.21 |
| Hy | 1.66 | 1.57 | 1.06 | 1.43 |
| Hy × KR | 1.51 | 1.28 | 0.94 | 1.24 |
| KR | 1.50 | 1.39 | 0.99 | 1.29 |
| KR × PR | 1.85 | 1.36 | 0.98 | 1.40 |
| PR | 2.93 | 2.04 | 1.41 | 2.13 |
| PR × $R_4$ | 2.17 | 1.63 | 1.15 | 1.65 |
| $R_4$ | 2.42 | 2.01 | 1.47 | 1.97 |
| PR × KR(Osf) | 1.60 | 1.25 | 0.95 | 1.27 |
| Mean | 1.85 | 1.52 | 1.08 | 1.48 |

TABLE 12.—*Analysis of variance based on top-root ratios, test 5.*

| Source of variation | Degrees of freedom | Mean square |
|---|---|---|
| Replications | 7 | 0.08 |
| Lines | 9 | 2.55** |
| Cultures | 2 | 12.07** |
| Lines × cultures | 18 | 0.24** |
| Error | 203 | 0.02 |
| Total | 239 | |

**P less than 0.01.

The results are similar to those of test 4. Mean top-root ratios for individual hybrids were again very similar in size to those of their low ratio parents. This held true whether individual hybrids were composed of two relatively high, two low, or a high and a low ratio inbred. That hybrid ratios as a group were slightly lower than those of their low ratio parents is evident in Table 13. The mean difference based on all three cultures was $+0.29 \pm 0.11$ which is significant at the 5% level. As in test 4, soil was the only individual culture on which hybrids had a significantly lower mean ratio than that of their low ratio inbreds.

The fact that a greater difference existed between $F_1$ hybrids and their low or high ratio inbreds when grown on soil as compared with the other two cultures, accounts for part of the significant interaction of lines × cultures ($0.63-(-0.02+0.24)/2 = 0.52 \pm 0.23$ for hybrids compared with their low ratio parents, $0.69 \pm 0.23$ for hybrids compared with their high ratio parents). Several other significant comparisons were found, but no consistent results pointing to inherited differences between inbred and hybrid ratios were discovered.

TABLE 13.—*Mean differences in top-root ratios between hybrids and their high ratio parents and between hybrids and their low ratio parents, test 5.*

| Hybrid | Culture | | | Mean |
|---|---|---|---|---|
| | Water | Soil | Sand | |
| High Ratio Parent Minus Hybrid | | | | |
| KR(Osf) × Hy | +0.27 | +0.27 | +0.11 | +0.22 |
| Hy × KR | +0.15 | +0.29 | +0.12 | +0.19 |
| KR × PR | +1.08 | +0.68 | +0.43 | +0.73 |
| PR × $R_4$ | +0.76 | +0.41 | +0.26 | +0.48 |
| PR × KR(Osf) | +0.82 | +0.76 | +0.52 | +0.70 |
| Sum | +3.08 | +2.41 | +1.44 | +2.28 |
| S. E. of sum | ±0.19 | ±0.19 | ±0.19 | ±0.11 |
| Low Ratio Parent Minus Hybrid | | | | |
| KR(Osf) × Hy | +0.15 | +0.03 | −0.07 | +0.04 |
| Hy × KR | −0.01 | +0.11 | +0.05 | +0.05 |
| KR × PR | −0.35 | +0.03 | +0.01 | −0.10 |
| PR × $R_4$ | +0.25 | +0.38 | +0.32 | +0.32 |
| PR × KR(Osf) | −0.06 | +0.08 | −0.07 | −0.02 |
| Sum | −0.02 | +0.63 | +0.24 | +0.29 |
| S. E. of sum | ±0.19 | ±0.19 | ±0.19 | ±0.11 |

Grades based on the relative coarseness of the root systems were taken in the same manner as were those in test 3. Results are given in Table 14. Hybrids were either intermediate or as coarse as the parent with the coarser type of roots.

TABLE 14.—*Mean root grades based on texture, test 5.*

| Line | Culture | | |
|---|---|---|---|
| | Water | Soil | Sand |
| KR(Osf) | 4.0 | 2.9 | 4.1 |
| KR(Osf) × Hy | 4.4 | 4.0 | 4.1 |
| Hy | 3.5 | 2.9 | 3.8 |
| Hy × KR | 3.3 | 4.8 | 4.0 |
| KR | 3.5 | 3.9 | 4.9 |
| KR × PR | 3.1 | 3.3 | 2.9 |
| PR | 2.3 | 2.5 | 1.5 |
| PR × $R_4$ | 3.6 | 3.6 | 2.6 |
| $R_4$ | 2.8 | 1.6 | 1.9 |
| PR × KR(Osf) | 3.9 | 3.8 | 3.5 |

## DISCUSSION

In order for plants to have survived under the force of natural selection there must be some mechanism controlling the balance between top and root growth. In the present investigation, by the use of homozygous inbred lines of corn and controlled environmental

conditions, it has been demonstrated that rather large inherited differences in top-root ratios may exist within a species. Although top-root ratios were altered for all strains by different environments (soil, low nutrient sand, and nutrient water cultures as growing mediums), inbreds occupied approximately the same rank from one environment to another. Inbreeding has thus isolated genes which tend to control the proportion of tops to roots. That several genes are involved is evident from the fact that when numerous inbreds were grown under similar environmental conditions they displayed a continuous range of ratios rather than a few distinct classes.

Top-root ratios for $F_1$ hybrids of inbred lines possessing different ratios either did not differ or were only slightly different from those of their lower ratio parents in all cases. This was true whether the hybrid combination consisted of a high and a low, two high, or two low ratio inbreds. Such results would indicate a dominance of factors for low top-root ratios.

Thus, a hybrid, despite the fact that it may show hybrid vigor and produce more total top growth than either parent, will still produce enough roots so that the proportion of roots to tops is similar to that of the parent possessing relatively more roots. This is of distinct advantage both from the standpoint of lodging resistance and nutrient absorption. Since the proportion of tops to roots is the same for hybrids as for their low ratio parents, the necessity of selection for strong-rooted inbreds is apparent if it is desired to obtain hybrids with relatively large root systems.

Smith (9) found dominance in inheritance of the branched root type. Since it has been shown in this study that hybrids have as much root weight per unit of top weight as have their stronger rooted parents, it may be assumed that the absorbing surface of hybrid roots per unit of top weight is at least as great as that of their inbred with the largest surface.

Interactions of lines × cultures were significant for all tests. It is entirely possible that in individual lines there are genetic factors which cause the top-root ratio response to culture to be different than the group response. No attempt was made to study this point.

## SUMMARY

Testing 21 different inbred strains of maize, heritable differences in top-root ratios, based on dry weights, were exhibited in each of three tests. Plants were grown for 4 to 6 weeks in the greenhouse on the three culture mediums soil, low nutrient sand, and nutrient aqueous solution.

The range of inbred ratio means in each test was large with individual line means being distributed uniformly throughout these ranges. This was interpreted to indicate that several genetic factors control top-root ratios.

Lines common to two or more tests occupied, in general, the same relative rank in ratio size in each test. Inbreds displayed approximately the same rank from one culture to another.

$F_1$ hybrids produced top-root ratios approximately equal in size to those of their low ratio parents. This was interpreted to indicate

dominance of genetic factors for low top-root ratios. Reciprocal hybrids, included in one test, did not differ significantly in top-root ratios.

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# EFFECT OF BORON DEFICIENCY ON THE SOLUBLE NITROGEN AND CARBOHYDRATE CONTENT OF ALFALFA[1]

P. N. SCRIPTURE AND J. S. MCHARGUE[2]

LITTLE is known as to the function of boron in plant growth and metabolism. The purpose of the investigation described in this paper was to determine whether boron is a factor in the absorption of nitrogen and the synthesis of carbohydrates. The present investigation is limited to the water-soluble nitrogen and carbohydrate fractions of the alfalfa plant tissues.

## CULTURAL METHODS

The alfalfa plants were grown in the greenhouse in sand cultures. Ten 2-gallon, glazed earthenware jars were filled with purified quartz sand which had been washed with hydrochloric acid and distilled water. Each jar had a hole in the bottom to allow continuous drainage. The hole was covered with a watch glass before adding the sand. Twenty seeds of the Grimm variety of alfalfa were planted in the sand and after germination each culture was thinned to 10 plants of uniform size and vigor. Nutrient solution was supplied by the continuous-drip procedure described by Shive and Robbins (7).[3] The flow was so regulated as to keep the sand always moist. The cultures were washed at weekly intervals by flushing with distilled water. This is necessary to prevent accumulation of unused salts. The nutrient solution used consisted of the following: $KH_2PO_4$, 0.0015 molar; $MgSO_4.7H_2O$, 0.0022 molar; and $Ca(NO_3)_2.4H_2O$, 0.0019 molar.

Zinc and manganese were supplied at the rate of 1 p.p.m. each. Zinc sulfate ($ZnSO_4.7H_2O$) and manganous sulfate ($MnSO_4.4H_2O$) were used as sources of these elements. Sufficient iron was supplied as ferrous ammonium sulfate to prevent chlorosis from lack of iron. All chemicals were of reagent grade and were spectroscopically boron-free. Boron was supplied as boric acid to all cultures at the start of the experiment and at the rate of 0.5 p.p.m. of solution.

When the alfalfa plants were about 5 inches high, boron applications were discontinued on five of the cultures, but the other nutrients were left unchanged.

The first visible symptoms of boron deficiency were observed about 20 days after the application of this element was discontinued. The youngest leaves of the plants presented a slightly roughened and thickened appearance. Within a week, growth of the terminal buds had virtually ceased and the affected leaves presented the characteristic yellow and yellow-bronze colorations. At the time of sampling, 3 weeks later, the plants which had received boron continuously were nearly twice the size of the boron-deficient plants.

## METHODS OF CHEMICAL ANALYSIS

*Sampling.*—Sampling was done during days of clear weather. It being impossible to take all the samples on one day, care was taken so that all sampling was

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[3]Figures in parenthesis refer to "Literature Cited", p. 992.

done at the same hour each day. Since it was desired to study the composition of the soluble materials in the plant, a method for securing plant extracts described by Chibnall (2) was used. The plants were cut off at the surface of the sand and the green weight obtained at once. The material was then immersed in dry ethyl ether for 1 minute, removed, and the excess ether allowed to drain away. The material, wrapped in several thicknesses of cheesecloth, was then subjected to pressure of 6,000 pounds per square inch for 5 minutes in a Carver press. The residue was removed from the press, moistened with 0.002 N HCl, and after standing for 15 minutes, pressed again at the same pressure and for the same length of time. This treatment was repeated three times. All extracts were combined and boiled for about 1 minute to precipitate any heat-coagulable proteins, filtered into a 250-cc volumetric flask, and after cooling to room temperature, made to volume with distilled water. The extracts were kept in the refrigerator until the analytical work was completed.

According to Chibnall, the treatment with ether effects a plasmolytic action on the protoplasm of the plant cells so that it is possible to press out the water-soluble vacuolar material. The extract obtained in this experiment was a clear yellowish-brown colored solution which contained no chlorophyll.

Total nitrogen, ammonia nitrogen, amide nitrogen, nitrate nitrogen, direct reducing sugars, and reducing sugars after hydrolysis with invertase were determined in the extract.

*Total nitrogen.*—Since the extracts contained nitrate nitrogen, it was necessary to use a modified Kjeldahl method. The iron reduction method of Pucher, Leavenworth, and Vickery (6), carried out on a micro-scale using 5 cc of the extract, was used. A micro-distillation apparatus described by Kirk (4) was used for the distillation. The distillate was collected in an excess of standard 0.02 N $H_2SO_4$ and the excess acid back-titrated in the usual manner.

*Ammonia nitrogen.*—Ammonia was determined on 10 cc of the extract in the aeration tube of the Van Slyke-Cullen urea apparatus made alkaline with 52% potassium carbonate and aerated for 1 hour. The ammonia liberated was distilled into 0.02 N $H_2SO_4$ and the excess acid back-titrated. Several drops of tributyl citrate effectively prevents foaming during aeration.

*Amide nitrogen.*—Nitrogen present as asparagine or other similar amide compound was determined by mild acid hydrolysis. A 10-cc aliquot of the extract was boiled in the Van Slyke-Cullen aeration tube with 0.6 cc of concentrated $H_2SO_4$ for 2½ hours, under a reflux condenser to maintain the volume of solution constant. Addition of several porcelain chips prevents serious bumping. After the hydrolysis, the tube and its contents were cooled to room temperature and neutralized with 40% sodium hydroxide, using methyl red as an indicator. From this point the determination was carried to completion in the same manner as for the ammonia determination described above. The value found for ammonia nitrogen serves as a blank for the amide nitrogen determination.

*Nitrate nitrogen.*—Nitrate nitrogen was determined according to the Jones (1), modification of the Robertson method, using 5 cc of the extract. The method was conducted on a micro scale as described above for total nitrogen.

*Direct reducing sugars.*—The Phillips (5) modification of the Bertrand titration procedure was used. Ten cc of the extract in a 100-cc volumetric flask was made to about 50 cc with water, and 1 cc of saturated neutral lead acetate was added and thoroughly mixed. After standing 15 minutes, the solution was made to volume and filtered into a small Erlenmeyer flask containing sufficient dry sodium oxalate to remove excess lead completely. The flasks were covered and

placed in the refrigerator overnight to complete the precipitation of the lead. After filtering, 10-cc aliquots were taken for analysis. The procedure was standardized, using pure glucose.

*Reducing sugars after invertase hydrolysis.*—To 10 cc of the clarified extract, 5 drops of 10% acetic acid and 4 drops of invertase solution were added. The tubes were covered and allowed to stand overnight at room temperature (about 25° C). The amount of invertase required was determined by preliminary standardization of the method with C. P. sucrose. The results are calculated as reducing sugars found after hydrolysis.

## RESULTS OF ANALYSES

The results of analyses for the several soluble nitrogen fractions are presented in Table 1. Values are all given as percentages of fresh plant weight.

TABLE 1.—*Percentages of the soluble nitrogen fractions in fresh alfalfa plants.*

| Extract No. | Total soluble N, % | Ammonia N, % | Amide N, % | Nitrate N, % | N in other soluble forms, % |
|---|---|---|---|---|---|
| | | | Normal Plants | | |
| 1 | 0.1416 | 0.0013 | 0.0066 | 0.0259 | 0.1078 |
| 2 | 0.1024 | 0.0022 | 0.0075 | 0.0128 | 0.0799 |
| 3 | 0.1343 | 0.0020 | 0.0053 | 0.0144 | 0.1126 |
| 4 | 0.1380 | 0.0013 | 0.0061 | 0.0121 | 0.1185 |
| Mean... | 0.1291 | 0.0017 | 0.0064 | 0.0163 | 0.1047 |
| | | | Boron-deficient Plants | | |
| 1 | 0.1963 | 0.0028 | 0.0320 | 0.0038 | 0.1577 |
| 2 | 0.1562 | 0.0026 | 0.0173 | 0.0000 | 0.1363 |
| 3 | 0.2293 | 0.0022 | 0.0233 | 0.0074 | 0.1964 |
| 4 | 0.1905 | 0.0021 | 0.0180 | 0.0002 | 0.1702 |
| Mean... | 0.1931 | 0.0024 | 0.0227 | 0.0028 | 0.1652 |

The results of analyses of the extracts for direct reducing sugars and reducing sugars obtained after hydrolysis with invertase are given in Table 2. All values are given as percentages of the fresh plant weight.

The results presented in Tables 1 and 2 were examined statistically and the mean differences in various constituents determined in the normal and boron-deficient plants were found to be significant.

## DISCUSSION

The abnormal accumulation of total soluble nitrogen and sugars in the boron-deficient plants suggests that protein metabolism may not be proceeding normally, as proteins are usually formed when amides, such as asparagine, and sugars are both present in excess. It may be that boron plays some part in this reaction since it is known to have considerable affinity for compounds having OH groups, such as alcohols and carbohydrates.

TABLE 2.—*Percentages of direct reducing sugars and additional reducing sugars after hydrolysis in fresh alfalfa plants.*

| Extract No. | Direct reducing sugars, % | Additional sugars after hydrolysis, % |
|---|---|---|
| Normal Plants | | |
| 1 | 0.3820 | 0.2576 |
| 2 | 0.4306 | 0.4598 |
| 3 | 0.5115 | 0.3210 |
| 4 | 0.3645 | 0.3705 |
| Mean | 0.4222 | 0.3522 |
| Boron-deficient Plants | | |
| 1 | 0.6930 | 0.5111 |
| 2 | 0.6869 | 0.2995 |
| 3 | 1.0260 | 0.6475 |
| 4 | 0.7198 | 0.5676 |
| Mean | 0.7814 | 0.5064 |

On the other hand, storage proteins may be disintegrating in the affected leaves and terminal buds that die. This could account for the accumulation of soluble nitrogen but not necessarily for the excess sugars; for though the carbon chains for the protein molecules may be derived from sugars, it is not probable that the sugars are regenerated when the proteins are split by enzymatic activity.

Johnston and Dore (3) in their work with boron-deficient tomato plants found that sugars accumulated in the leaves but not in the stems. They concluded that the sugars accumulated because the conducting tissues of the leaves and stems were injured by the lack of boron and were no longer able to function in transporting materials from the leaves to other parts of the plant. Studies by Warington (8) on the broad bean and other plants indicate that a lack of boron does cause injury to the phloem cells. Johnston and Dore did not investigate the nitrogen relationship in the tomato plant so no comparison is available on this point.

A considerable difference in the content of nitrate nitrogen was also found. The boron-deficient plants were apparently able quickly to reduce absorbed nitrates to ammonia and thence to amide or other soluble nitrogen compounds. Whether boron is involved in these transformations is impossible to state with the information at hand.

Further work on these nitrogen-carbohydrate relationships will be necessary in order to verify these hypotheses.

## SUMMARY

1. Alfalfa was grown in purified sand culture in the greenhouse under conditions where boron was deficient. Extracts of the plant tissue were obtained by means of a press and analyzed for nitrogenous constituents and reducing sugars.

2. Soluble nitrogen compounds, including amides, ammonia, and nitrogen in other forms, were found to be present in larger proportions in the boron-defficient plants than in those growing normally.

3. Sugars were found to be present in excess in the boron-deficient plants.

4. The possibility that boron may be involved in protein metabolism is suggested.

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# BOOK REVIEWS

## PLANTS AND VITAMINS

*By W. H. Schopper; translated by Norbert L. Noecker. Waltham, Mass.: Chronica Botanica; New York: G. E. Stechert and Co. XIV+293 pages, illus., 1943. $4.75.*

THIS excellent book dealing with the importance of vitamins as related to plants is now presented in an English edition. Nearly ten years have passed since Professor Schopfer presented evidence that a specific chemical factor, thiamin, was necessary for the growth of certain plant life. As a result of his findings, interest in the significance of vitamins to plant growth was widened and this book is a collection of the author's studies and a review of the researches which have resulted from them. No effort has been made to mention all publications dealing with plants and vitamins, but only those which are relevant to the subject discussed by the author are included.

The book opens with a discussion on research technic when studying growth factors, and reviews the problems encountered in the preparation of good synthetic media for growing the test plants. The difference between various organic substances which may stimulate growth and the true vitamin action are considered and the stimulator agents classified. The chemical and physiological properties of the present known vitamins are next reviewed before their action on the embryo, roots, tissue cuttings, and formation of plant organs is discussed. Considerable space is devoted to a consideration of thiamin and its components—a field in which the author is an authority.

Particularly noteworthy are two chapters on the synthesis of vitamins in plants, for while there is relatively little known about this phenomenon, the author has collected available information and presented general ideas. The history of the bios factors is dealt with in an interesting manner and the evidence for the chemical identity of these substances is presented in terms of our present knowledge of the vitamins of the B complex. The requirements of different types of bacteria, such as the lactic acid, nitrogen-fixing, and hemophilic organisms, are reviewed in terms of growth factors. An effort has been made to correlate the action of vitamins as coenzymes and also their relationship to plant and animal hormones.

The section dealing with the role of vitamins in agriculture, especially as nutrients found in the soil, merits inspection. Attention is also paid to the relationship of vitamins to sexuality, symbiosis, and parasitism. The concluding chapter concerns the utility of microorganisms in vitamin analysis where there is a rather unprejudiced discussion of the biological assay of thiamin.

The book should be of value to all interested in vitamins and plant growth and, in particular, to botanists and plant physiologists. Though the author might have been more direct in mode of discussion at times, in general, the arrangement of the material presented is good and the overlapping of subject matter is not serious when one considers the ramifications of vitamin functions throughout plant metabolism. (J. C. M.)

### ARTIFICIAL MANURES

*By Arthur B. Beaumont. New York: Orange Judd Pub. Co., Inc. 155 pages, illus. 1943. $1.50.*

THIS small volume by the former agronomist at Massachusetts State College is a simple and popular presentation of the importance of soil organic matter, manures of various kinds, and especially the making of composts and artificial manures for farm and garden use. The author first lays a simple background through a discussion of soils, soil formation and management, and the functions of organic matter and humus in agriculture. The Richards and Hutchinson method is then discussed with practical details of its use in both large- and small-scale operations. Some attention is also paid to green manuring and sheet composting.

The volume carries an index, an appendix with the composition of all kinds of materials usable in making manures, and a list of 26 selected references. It should prove useful and practical. (R. C. C.)

### "STUDENT'S" COLLECTED PAPERS

*Edited by E. S. Pearson and John Wishart, with a foreword by Launce McMullen. Issued by the Biometrika Office, University College, London, and printed by the University Press, Cambridge, XIV+224 pages, illus. 1942. 15/.*

IN READING this book the reviewer was impressed by four features, (1) the honoring of William Sealy Gosset ("Student") by his colleagues through bringing his printed contributions together

in one volume; (2) the excellent biography by McMullen; (3) the fine spirit of cooperation shown by the editors of various technical journals in granting permission for republishing the articles in the present volume and especially the Trustees of *Biometrika* for accepting the responsibility for publication; and (4) the value to statisticians everywhere of having these contributions in a single volume.

The publishing of Student's collected papers as a monument to this pioneer worker in small sample statistics will cause him to be more widely appreciated than could have been accomplished by the placing of a bronze tablet or by the erection of a stone monument. The editors are to be commended for the planning and execution of this idea. As one reads the biographical sketch of Mr. Gosset in the foreword he is impressed how much the book would have lacked had this and the photograph been omitted. Furthermore, one sees that Mr. Gosset was intensely practical and used statistics as a tool to evaluate his experiments rather than to use the experiments to display his prowess as a mathematician, a far different attitude than is evident in the writings of some biologists. His writings consist of 21 papers and a number of miscellaneous contributions.

Within the past 20 years numerous books dealing chiefly with small sample statistics have appeared in which the investigations of "Student" are discussed and references given to his published papers. Biologists attempting to use his methods before 1925 frequently had difficulty in locating his contributions and even then the securing of some of the publications in which the articles appeared was not an easy matter. The worker who did not have access to one of the large university libraries was handicapped. The present volume overcomes this difficulty and doubtless will enable many workers to study a number of "Student's" contributions for the first time. Not only are all his published papers reprinted but numerous supplementary discussions of papers by other workers are given, including remarks made at meetings of biometricians. In short, we are now given "Student's" writings complete as a reference work, a fitting tribute to this hewer of a new pathway which has been broadened into an important road for those who must use small samples, as is true of many agricultural investigators. The publishers are to be commended for their efforts in producing a first-class example of printing and binding. (F. Z. H.)

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# AGRONOMY AND HUMAN BEINGS[1]

F. D. KEIM[2]

TONIGHT we are assembled in the thirty-sixth annual meeting of the American Society of Agronomy. During the past 36 years American agriculture has gone through most of the trials and troubles that could confront a great democracy. We weathered a world war, enjoyed one of the greatest boom periods in history and suffered through a depression coupled with a terrific 10-year drouth that rocked the nation. Some scars remain but many lessons were learned.

Today we are again involved in a world war. Its requirements for food, man-power, and expenditures of public money make the last world struggle appear small. Through war and peace the American agronomist has played an important role and has tried to live up to the standards and ideals laid down in 1907 by the founders of the American Society of Agronomy.

Carleton (1)[3] in his presidential address in 1908 said of this organization, "The first association of the kind in America, and one that will have, without question, a tremendous influence on agricultural investigation and practice." Thorne (6) remarked in 1915, that, "The ultimate purpose of the work of the scientific agronomist is to increase the production of food and clothing for humanity." Jardine (2) wrote, "Men must be fed and clothed before they can fight. A continuous stream of food stuffs must be kept moving from this country and Canada to our allies and the allied armies at a time when not only is the world's available food supply low but the stores of wheat in Russia, India, and Argentina are inaccessible. Especially heavy, therefore, is the responsibility resting upon American Agriculture." This last quotation written in 1917 sounds so familiar that it could have been written in 1943.

There have been times during the past 36 years when the agronomist was accused of contributing too liberally to the food supply of the nation and agronomists, like many other scientists, were not in great demand. Today the world is again clamoring for more food,

[1]Presidential address delivered at the annual meeting of the Society in Cincinnati, Ohio, November 11, 1943.

[2]Chairman, Department of Agronomy, University of Nebraska, Lincoln, Nebr.

[3]Figures in parenthesis refer to "Literature Cited", p. 1001.

but sufficient agronomists and other thoroughly trained men are not available. As was the case during the last war, the agronomist has inventoried the seed supplies of the nation. He has headed campaigns for increased crop acreages. He has served on all kinds of committees that relate to food production and the war. The Society maintains an important committee on war and post-war adjustments. The 1942 report of this committee (4) is well worth rereading. The 17 recommendations made on the agronomist's position in the war and the post-war period are truly illuminating. In addition to these activities the agronomist is called upon for information on almost every conceivable point relating to agriculture, which he attempts to give through teaching, correspondence, public addresses, and the press.

The agronomist is not only thinking of the present emergency, but he is also looking forward into the future. He is contributing his full share to the conservation of the natural resources of the country so that human beings will continue to be sheltered, clothed, and fed. A strenuous effort is being made to increase production to the limit, but at the same time the agronomist hopes to avoid the dust storms and unnecessary erosion which followed as an aftermath of the last war and great drouth.

As is evidenced by the interest taken in nutritional research, he is not to be satisfied with providing food alone for humanity, but he is interested in the general field of nutrition and desires to supply the best of balanced rations. Again the agronomist expresses his interest in all those products that may be forthcoming from farm crops and thus increase their value and usefulness to industry and agriculture in the post-war period.

May I illustrate the importance of agronomic work to humanity by using an example from my own state. A like illustration could be taken from every state in the Union. During the past two years, the Nebraska Agricultural Experiment Station, with the cooperation of the U. S. Dept. of Agriculture, has thoroughly tested and made available for certification by the Nebraska Crop Improvement Association 21 new crop varieties. It has thus made these pure seeds available to the Nebraska farmer. These consist of Pawnee winter wheat; Otoe, Cedar, Fulton, and Trojan oats; Ezond barley; Dunfield and Illini soybeans; Ranger alfalfa; Lincoln bromegrass; Madrid, Spanish, and Evergreen sweet clover; Biwing flax; and seven corn hybrids, U. S. 13, U. S. 35, Illinois 201, Indiana 608C, Iowa 4059, Iowa 306, and Ohio 92. If these are added to some 20 other crop varieties that previously have been made eligible for certification, the Nebraska farmer has a large number of superior crops from which to choose.

It is worthwhile to consider just what these choice varieties of farm crops mean to the wealth of the state in which they are released. Increase in yields alone, to say nothing about better quality of these highly selected crops over the old original varieties, will range from 10 to 20%. This means 10 to 20% more cash grain and 10 to 20% more grain, hay, and forage to feed the livestock of Nebraska. Since nearly every state can show much the same ac-

complishment along this particular line, the cash grain and feed made available by this experimental work is tremendously important any time and especially in the war emergency.

Two specific examples will suffice to make more clear what this means to our wealth. Pawnee wheat is the result of a Kawvale × Tenmarq cross made at the Kansas Agricultural Experiment Station. One hundred and thirty-eight plant selections were obtained by the Nebraska Agricultural Experiment Station from among which Pawnee was finally selected. At Lincoln for seven years (1936–1942) Pawnee has had an average yield of 28.4 bushels per acre compared with 21.8 for Turkey, an increase of 6.6 bushels per acre. This wheat is especially adapted to the southeastern part of Nebraska where farmers annually grow at least 1,000,000 acres. If all farmers, in this area planted Pawnee, total wheat production would be increased approximately 6,600,000 bushels. At $1.25 per bushel this would add to the wealth of the area 8¼ million dollars.

From a mere beginning in 1933, hybrid corn now dominates corn production in the United States. In 1943 approximately 50 million acres, nearly 52% of the total corn acreage of the country, was planted to hybrid seed. This represents our best corn land and probably produced at least three-fourths of the entire crop. Calculating on a basis of 20% increase due to hybrid development, the total production of corn in the United States has increased approximately 375 million bushels. Such accomplishments, reaching their xenith just at this time, make it possible to meet the unprecedented demands of supplying food and clothing to our Allies as well as adequately providing for our own people.

There could be many more similar examples. Richey (5) in his presidential address in 1937 entitled, "Why plant research?", covered many of them very thoroughly. I should like to mention a few research projects and accomplishments that seem to me to be of great significance, as follows: (a) The possibilities along the line of native grass seed collection, production, and processing, and the cultural practices necessary to re-grass non-crop lands; (b) adaptation to local conditions of strains of bromegrass and other cultivated and native grasses; (c) vegetation surveys and practical applications made in range and pasture management; (d) use of grasses in rotation in semi-humid to semi-arid regions and their effect on production, erosion, soil tilth, and other farm management practices; (e) the development of hybrid alfalfa, bromegrass, and other distinct plant improvement through breeding; (f) advances in the knowledge and dissemination of this knowledge on perennial weed eradication and control methods; (g) the manufacture, methods of application, and use of fertilizers adapted to the many soil types and conditions in the United States; (h) the tremendous growth of soil conservation districts in the nation and the advance in good farm management practices and land utilization that are accruing from these operations; (i) and finally the wealth of technical research that contributes to the knowledge of fundamental physical, chemical, and biological science. One could continue at length citing research results and the needs that lie ahead, but there is another phase of

this subject of agronomy as it relates to human beings that always has been a hobby of mine.

Two important opportunities confront every department of agronomy. First, there is the training of outstanding men for teaching, research, and other agronomic activities. Second, there is the completion and publishing of essential and valuable research results. It is the quality and quantity of the results of these two functions that determine the national rating of any department. The second function, quality and quantity of research, has been considered briefly earlier in this discussion. It is my desire now to direct attention to the training of good men.

I honestly think that college and station agronomists in most of the states have given this subject a great deal of thought. The general level of agronomic personnel over the country has made a phenomenal improvement. Most modern agromonists have appreciated the value of the fundamental sciences, such as chemistry, physics, mathematics, geology, and all the branches of biological science, in solving their problems. Students soon recognize this and the cream of the crop naturally gravitate into this type of intellectual atmosphere. In order to facilitate such a migration, it is necessary to have outstanding teachers for freshmen and undergraduates. These teachers do not need necessarily to be great research workers, but they must have this fundamental science knowledge and be able to instill its need into the minds of their students. Much has been written on this subject. In 1937 I (3) discussed the agronomy teacher and his training at some length. I feel now more than ever that a very great responsibility rests upon the shoulders of the undergraduate teacher. It is he who will choose and do much of the training of the embryonic agronomists. He must recognize early the student with outstanding ability. It is in the upper 5 or 10 among 100 students where the teacher is most likely to find the scholarly man whom he should encourage to continue in training and go into the profession. This scholarly young man should not be an oddity. It is preferable that he be normal in size, of good appearance, and have high personal quality. He should show signs of leadership and be able to get along with his associates and others with whom he comes in contact. He should have unusual capacity for hard work and show early in his career the capacity for completed accomplishment.

A characteristic that is frequently overlooked in choosing the prospective agronomist is the quality which the student possesses of noting the value of little things. If a young assistant can sense the presence of angoumois moths, mice, and other laboratory pests and remove the source without being told; if he has a knack of cleanliness about the teaching or research laboratory; if he handles the departmental cars, trucks, and other equipment in peace times as war time demands—he has something that will make him valuable to any department in which he may later be employed.

A few years ago I was watching a farmer's fair parade staged by the students of the Nebraska College of Agriculture. Numerous tractors and trucks were being driven by these students. On one of the drives a fair sized hole had been previously worn in the pave-

ment. It had rained and this hole was full of muddy water. Driver after driver hit this hole with one of the tractor wheels. Occasionally a few of the drivers would make an effort to avoid hitting the hole. In every case where this effort was made an outstanding student was at the wheel. This, of course, is a minor thing, but it does show a quality of carefulness and thoughtfulness that is important.

The undergraduate teacher has a real responsibility in administering a college curriculum. Unless he has a thorough knowledge of the contents of courses in his own field and a wide knowledge of supplementary courses necessary to round out the training of this young student, the time will come for graduation and much-needed training will be missing. I thoroughly agree with Throckmorton (7) that too much early specilization in a student's career should be avoided, and that basic courses in the sciences related to agriculture are very important. Nevertheless, it is amazing how many different lines of opportunities are developing for agronomy majors. It seems to me that to best prepare a student for one of these special opportunities, the fundamental and specialized training must differ materially.

Many times I have attempted to arrange a curriculum that would offer the best training for the various agronomy lines such as the soil chemist, soil bacteriologist, soil physicist, soil surveyor, soil conservationist, the plant breeder, technical geneticist, range examiner or surveyor, land appraiser and farm manager, food and feed processor, hybrid corn production manager, seed certification manager, county agent, extension agronomist, the college teacher, and the so-called scientific farmer. I admit that the first two years of the curriculum should remain much the same, but the junior and senior years differ rather widely. This is not due entirely to the training needs of the student for these various lines of work, but partly because young men differ so much in temperament and aptitudes. If they can be directed to the proper niche and assigned courses of study that coincide with their desires, their chances of success are infinitely better. It takes a wise undergraduate teacher to sift young men into these different categories and plan their schedules accordingly. It takes patience and long hours of after-class discussion, but it is worth while.

I have seen students flounder for months trying to decide on just what line of agriculture they wished to follow. Many times I have asked them this question, "If you had your choice of all the jobs in the world just what would you choose?" Frequently this question crystalizes their thinking and before long they are able to make rather definite decisions. I also try to assure them if they do a good job in whatever they undertake, other things are more likely to work out, so that too definite choice is not necessary.

I remember one amusing case. This young man was a brilliant student and possessed a personality that would take him anywhere. He tried soils and then genetics but he did not click. He received his degree but as a scientist he was impossible. When he graduated, an opportunity came along as a salesman for a large chemical and insecticide concern. He took it rather reluctantly. In less than a

month he was perfectly contented and bubbling over with enthusiasm. He had finally found his niche.

The undergraduate teacher has the responsibility of selling himself and his product and the finest incentive for knowledge is a feeling of the need of that knowledge. Do we as teachers point out this need to the student as much as we should? Too many teachers throw a subject at a student without pointing out the wonderful possibilities that will accrue if proficiency is attained.

It is difficult at times for the full-time research man to realize the value of apprentice training for graduate and undergraduate students. The earlier a young man who shows the proper caliber for an agronomist can be used as a student assistant in teaching or experimental work, the broader will be his knowledge when he receives his degree. Here again patience and an aptitude on the part of the teacher or research worker for training these young men should be encouraged. If the man in charge of a project is a lone wolf and does not have this aptitude, it will probably be better not to assign younger students to him for part-time work.

The young agronomist should be encouraged to become really proficient in English. His ability to express himself before the public, in the writing of research papers and the many popular articles and letters which he will be called upon to write, will be a great satisfaction to him and to the department which he represents.

Attendance at conferences and other scientific group meetings for both graduate students and faculty should be encouraged. The progress of research in many special fields has advanced with rare rapidity due to such conferences. Months of time can be saved by the exchange of ideas. The general knowledge and presentation of subject matter and the acquaintance made with colleagues makes meetings and conferences of untold value to the student and research representative.

There is one other phase in the training of this agronomy student that I want to emphasize. It is probably more important than the academic training. This is the moral and character-building qualities that he should develop in his life. Here the teachers again play an important role. I recently made this statement in regard to the late Dr. A. L. Frolik, "Frolik believed that every teacher should be a living example of all character-building principles. His popularity, enthusiasm, and salesmanship caused most of his students to copy these high standards and build them into their lives."

Recently, Dr. T. H. Goodding and I checked back over 54 students making up our Nebraska crop judging and identification teams. Only 3 of the 54 who participated in the activity were addicted to the usual forms of intemperance. Moderation is the key word of character. I am interested in the student who believes in temperance in word and act; who does not indulge in too much drinking, if any, of course, but equally never too much eating, scolding, laughing, dancing, smoking, reckless driving—never excess at all. This quality gives a student a freedom that often accelerates his progress, and still more important, it is an indication that he possesses the fine quality of self control. Another indication of the

character-building qualities of the student is his religious activity. Leadership in church activity is almost sure to add to a student's value during the time he is in school and after he gets out on the job. The communities that make up the world need this kind of leadership, and the agronomist should contribute his bit. If our profession is to wield its influence on humanity to the greatest possible degree, no aspect of character and leadership can be overlooked in training the young agronomist. A department or institution can not be any greater than the men and women who make up its personnel.

The fruits of research and teaching must be translated eventually into action on the farm and in industry. Unless this is done the work of the agronomist as such will have been in vain. To speed this translation into action the extension agronomist plays a prominent part. In training future agronomists this service and activity should receive as much attention as any other.

The end of all research, teaching, and extension in agronomy is to improve the status of agriculture and to provide human beings with an abundance of farm products of the most acceptable kind and quality, at a minimum cost. In other words, we agronomists have the job of doing our share to see that people have an opportunity to live better in a better world.

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# THE SORPTION-BLOCK SOIL MOISTURE METER AND HYSTERESIS EFFECTS RELATED TO ITS OPERATION[1]

L. A. Richards and L. R. Weaver[2]

Davis and Slater (1)[3] in a note to this Journal described a "direct weighing method for sequent measurement of soil moisture under field conditions". Independently the authors have been working on a moisture meter using the same principle and, although our results are not complete or conclusive, all the information we have obtained appears to be favorable to the method. Since our work on this project has been interrupted by the war, it is the purpose of this paper to report the progress we have made.

The method is based on the fact that a suitably disposed porous block will sorb (sorbeo—to suck in) moisture and come to equilibrium when placed in contact with moist soil. The rate at which equilibrium is attained and the degree of correspondence between the weight of the sorption-block and the moisture content of the soil are pertinent to the success of the method.

## APPARATUS

Of the various forms of the apparatus tried by the authors, that shown in Fig. 1 appears to be the most promising. A piece of tubing (A) inserted in the soil serves as the mounting for the system.[4] The soil surface at the bottom of the tube is leveled, packed gently, and covered by a disc of long fiber asbestos paper (B) which is cemented to the top of a short section of thin-walled brass tubing (c). This asbestos (0.008 inch thick) should be washed in water to remove sizing material. Three short legs of copper wire (D) soldered to the inside of the ring help to keep the asbestos cover in place. The sorption block (E) consists of a short cylinder of porous ceramic material mounted on a brass pin and covered with a disc of mica. We have used 36 gage copper wire rolled to a ribbon for the suspension.

A No. 5 rubber stopper (F) is mounted on the end of a section of steel tubing (G) (3/8 inch outside diameter, $\frac{1}{32}$ inch wall). A washer is soldered on the tube to transmit the thrust to the stopper. The rubber stopper serves the double purpose of making a vapor seal to the sorption block chamber and also supplies a continuous elastic force to hold the block in contact with the soil when the small tube is lowered and clamped in place by the set screw in the threaded

[1]Contribution from the U. S. Regional Salinity Laboratory, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, Riverside, California, in cooperation with the eleven western states and the Territory of Hawaii. Received for publication June 2, 1943.

[2]Senior Soil Physicist and Agent, respectively. The authors are indebted to P. E. Skaling for assistance with the experimental work on this project during the spring and summer of 1941.

[3]Numbers in parenthesis refer to "Literature Cited", p. 1011.

[4]We have used 1-inch thin-walled steel electrical conduit tubing. The inside of the lower end must be polished and carefully coated with tin or solder to prevent corrosion. The rest of the interior should be freed from burrs and coated with waterproof paint.

collar. A disc of mica (H) supports the upper end of the suspension and also helps to exclude extraneous material from the sorption block chamber. The turned wood cap (I), which is impregnated with paraffin, forms a closure for the top of the system and has a felt insert (J) to make a dust seal.

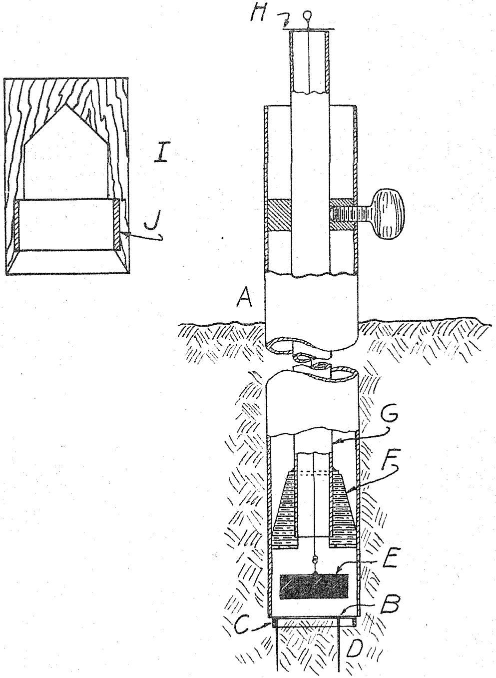


FIG. 1.—Sorption block assembly for a soil moisture meter.

We have used sorption blocks ¾ inch in diameter and ¼ inch thick which were plaster cast from a slip made from 90% common brick earth and 10% diatomaceous earth. After drilling holes for the brass pins, the blocks were brought to 850° C in an electric muffle furnace

and allowed to cool. Abrasion of the blocks during handling was effectively prevented by lightly vitrifying the peripheral surface with an acetylene torch.

The sorption block weighings can be quickly made. The procedure is simply to (a) remove the wood cap, (b) unclamp the set screw and raise the rubber stopper (shown in the raised position in Fig. 1) and, (c) mount the weighing device on the top of the tube and attach the suspension system.

## EXPERIMENTS

A preliminary experiment was set up in a constant temperature room ($21^\circ \pm 1.0^\circ$ C) to get information on the rate of transfer of water between sorption blocks and soil. Four 4-gallon crocks were filled with Fallbrook loam at four different moisture contents ranging from 15-atmosphere-percentage (near the wilting percentage) to the third-atmosphere-percentage (near the moisture equivalent). The soil for the crocks at low moisture levels was thoroughly mixed during and after wetting and was packed to field density. Three sorption block tubes were installed in each crock, the soil surface was heavily sealed with paraffin, and the pots were allowed to stand several weeks to approach equilibrium before experiments were started. The sorption-block installations were similar to those shown in Fig. 1. An analytical balance supported on a track was used for the weight measurements and weighings were made to 0.1 milligram. Lack of change of weight of each sorption block was considered indicative of equilibrium between block and soil.

Results from a considerable number of measurements may be summarized as follows:

1. Blocks saturated with water come to constant weight in wet soil in less than a day.
2. Dry blocks come to constant weight in wet soil in less than 3 days.
3. Wet blocks come to constant weight in dry soil in less than 5 days.
4. Blocks transferred between adjoining moisture levels either wetter or dryer generally reach equilibrium within 2 days.
5. For blocks having the composition given above there was found to be a hysteresis effect. That is, the equilibrium weight of a given block in a given soil depended on whether the block initially was wet or dry. This hysteresis effect was largest in wet soil. If the variation in the weight of the block from saturation to the wilting condition is taken as 100%, the block weight at equilibrium in wet soil (½ atmosphere tension) was found to vary through approximately 4% of this range, depending on whether equilibrium was approached from the wet or the dry side.

## SORPTION-BLOCK OPERATION UNDER PLANTS

Sorption-block assemblies like those shown in Fig. 1 were installed at a depth of 6 inches in 4-gallon crocks containing Fallbrook loam. The crocks which were planted to maize and placed in the greenhouse are shown in Fig. 2. Block weight readings were taken usually just once daily between 8 and 9 o'clock in the morning. Fig. 3 shows


FIG. 2.—Sorption-block moisture meters in greenhouse pots. The photograph shows the condition of the maize on July 21, one day after irrigation.

the gross weight vs. time curves for these four moisture meters. When the plants were badly wilted, enough water was applied to the pots to produce some drainage outflow. The open circles on the curves indicate the day on which the plants developed wilting symptoms before noon. Fig. 2 shows the condition of the plants on July 21, one day after irrigation. It is seen that block weight corre-

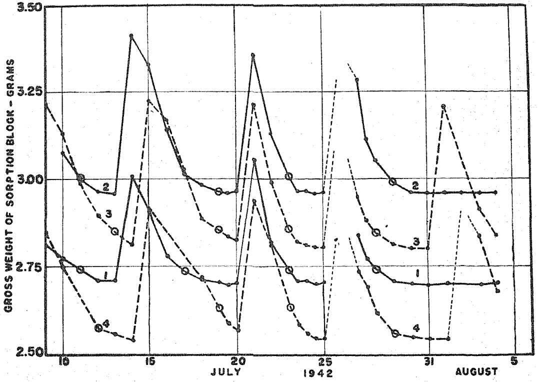


FIG. 3.—The variation of sorption block weight with time. The blocks were installed at a depth of 6 inches in four soil pots in which maize plants were grown. The open circles on the curves (one curve for each pot) indicate the days when wilting occurred before noon.

lates nicely with wilting, the variations in the weight of a block at the successive wiltings being generally less than weight losses during one day's time. There is reason to believe the blocks were not lagging far behind the soil even under these conditions of rapid soil moisture extraction. It is seen further that after permanent wilting the block weight soon attains a minimum value and that this minimum is the same for subsequent dryings. For the sorption blocks used in this experiment this minimum weight was not far above the oven-dry weight so these blocks were not suitable for studying moisture losses in the wilting range. Gross pot weight readings were not taken so the relation between block weight and soil moisture content was not established, but the curves in Fig. 3 resemble weight loss curves for soil pots containing plants (7).

It is seen that the range of moisture change for the blocks used is 300 to 400 milligrams. The gross weight of these blocks and suspension systems was kept small because the weight readings were made with a low capacity spring balance[5] free from the thermal effects. The authors have not studied the weighing problem sufficiently fully to make recommendations on a weighing device for general field use, but this appears to be only an incidental technical problem. In the future we plan to use sorption blocks about 3/8 inch thick.

## HYSTERESIS

In the absence of temperature gradients it appears that gravity and gradients in the equivalent negative pressure or soil moisture tension are chiefly responsible for the movement of water through soil and hence into and out of sorption blocks. The relation between the soil moisture content and soil moisture tension for the block and the soil is thus of some interest.

It appears to be well established experimentally that there is a hysteresis effect in the relation between soil moisture tension and moisture percentage (4). This is indicated by the moisture content differences found at the same tension for various soils as shown in Table 1. Fig. 4 is a graphical representation of the data for the Yolo fine sandy loam. The soils are surface samples, 0 to 6 inches, and the series names were taken from the soil maps. The Vale sample is from plot B of the alkali experimental plots of the Oregon Agricultural Experiment Station at Corvallis.

These results were obtained with 6-inch double-walled irrigator pots by a method which has already been described (4). The experiment was conducted at a temperature of $21 \pm 1°$ C and the equilibrium moisture content of the soil for the successive soil moisture tension values was calculated from the initially determined tare weight and the successive equilibrium gross pot weights. The soils were screened and packed in the pots at approximately field density. The initial moisture content and the date of starting of the experi-

[5]The spring was the Isoelastic type manufactured by John Chatillon Company. It was 0.32 cm in diameter and 12.5 cm long, with a spring constant of 5 cms per gram. A conventional jolly balance mounting was used and weighings could be quickly made to within ±2.5 milligrams. The authors have also used inexpensive jolly balance springs, but these are subject to temperature effects for which we did not wish to make adjustments in this preliminary work.

TABLE 1.—*Hysteresis data for six soils from western United States.**

| Equilibrium attained | Fallbrook loam S-40-1 | | | Ritzville loam S-40-18 | | | Yolo fine sandy loam S-40-23 | | | Indio very fine sandy loam S-40-4 | | | Vale plot B S-40-16 | | | Imperial clay S-40-3 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Date | Tension | Pw | Date | Tension | Pw | Date | Tension | Pw | Date | Tension | Pw | Date | Tension | Pw | Date | Tension | Pw |
| Start | Mar. 12, '41 | — | 4.17 | Mar. 11, '41 | — | 2.14 | Mar. 11, '41 | — | 9.02 | Mar. 11, '41 | — | 5.37 | Mar. 12, '41 | — | 12.40 | Mar. 12, '41 | — | 9.34 |
| 1 | June 12 | 610 | 5.23 | July 10 | 610 | 10.20 | July 10 | 610 | 17.16 | Aug. 5 | 609 | 12.49 | July 10 | 610 | 21.28 | June 12 | 610 | 28.28 |
| 2 | Aug. 18 | 305 | 5.86 | Oct. 27 | 306 | 13.14 | Sept. 30 | 304 | 19.10 | Sept. 30 | 305 | 14.65 | Sept. 30 | 304 | 23.90 | Aug. 18 | 305 | 29.71 |
| 3 | Jan. 7, '42 | 152 | 7.75 | Feb. 20, '42 | 153 | 19.60 | Dec. 23 | 154 | 22.00 | Dec. 23 | 153 | 18.50 | Dec. 23 | 153 | 27.97 | Oct. 15 | 153 | 31.89 |
| 4 | Feb. 20 | 2 | 23.05 | Mar. 20 | 0 | 39.01 | Feb. 20, '42 | 0 | 42.39 | Feb. 20, '42 | 0 | 40.09 | Feb. 20, '42 | 0 | 48.47 | Jan. 7, '42 | 0 | 52.31 |
| 5 | Mar. 25 | 153 | 14.44 | Mar. 25 | 153 | 33.47 | Mar. 20 | 152 | 25.47 | Mar. 20 | 153 | 28.62 | Mar. 19 | 153 | 34.17 | Feb. 20 | 152 | 35.24 |
| 6 | Apr. 1 | 306 | 8.54 | Apr. 1 | 305 | 18.53 | Mar. 24 | 305 | 22.46 | Apr. 20 | 306 | 24.05 | Mar. 25 | 305 | 29.37 | Mar. 20 | 305 | 32.83 |
| 7 | Apr. 17 | 610 | 6.02 | Apr. 17 | 611 | 12.77 | Apr. 1 | 610 | 19.82 | May 5 | 610 | 21.42 | Apr. 1 | 610 | 24.96 | Apr. 1 | 610 | 30.69 |
| 8 | Apr. 27 | 774 | 5.55 | Apr. 27 | 775 | 11.60 | Apr. 11 | 776 | 18.64 | May 29 | 777 | 19.22 | Apr. 8 | 777 | 23.27 | Apr. 8 | 776 | 29.79 |
| 9 | May 3 | 611 | 5.63 | May 12 | 611 | 12.15 | Apr. 27 | 611 | 18.72 | June 10 | 610 | 18.63 | Apr. 17 | 611 | 23.61 | Apr. 24 | 614 | 29.90 |
| 10 | May 12 | 306 | 6.53 | May 25 | 307 | 15.05 | May 5 | 305 | 20.24 | June 20 | 306 | 19.14 | Apr. 22 | 306 | 20.08 | May 5 | 305 | 30.95 |
| 11 | May 25 | 153 | 10.27 | June 15 | 153 | 21.80 | May 18 | 154 | 22.80 | June 26 | 152 | 19.90 | Apr. 27 | 153 | 30.15 | June 2 | 1 | 45.58 |
| 12 | June 10 | 1 | 20.06 | July 8 | 0 | 33.91 | May 29 | 305 | 20.97 | July 8 | 0 | 33.40 | May 5 | 0 | 42.56 | June 10 | 152 | 33.92 |
| 13 | June 20 | 153 | 13.34 | July 22 | 153 | 26.72 | June 10 | 610 | 19.10 | July 22 | 152 | 25.83 | May 12 | 153 | 31.99 | June 20 | 305 | 32.04 |
| 14 | July 1 | 306 | 7.63 | July 27 | 304 | 17.91 | June 20 | 776 | 18.60 | Aug. 3 | 306 | 23.12 | May 18 | 306 | 27.87 | July 1 | 612 | 30.09 |
| 15 | July 8 | 612 | 6.14 | Aug. 3 | 613 | 12.88 | June 24 | 611 | 18.68 | Aug. 10 | 611 | 21.59 | July 8 | 777 | 23.17 | July 8 | 777 | 29.64 |
| 16 | July 15 | 781 | 5.63 | Aug. 11 | 775 | 11.96 | July 8 | 306 | 20.17 | Aug. 20 | 776 | 20.07 | July 15 | 610 | 23.36 | July 15 | 611 | 29.75 |
| 17 | July 22 | 610 | 5.74 | Aug. 16 | 612 | 12.33 | July 15 | 610 | 18.95 | Aug. 26 | 610 | 19.64 | July 22 | 305 | 25.79 | July 22 | 296 | 30.84 |
| 18 | Aug. 3 | 305 | 6.73 | Aug. 22 | 306 | 15.38 | July 22 | 776 | 18.49 | Aug. 30 | 307 | 19.86 | July 29 | 153 | 29.93 | July 31 | 154 | 32.49 |
| 19 | Aug. 10 | 153 | 10.23 | Aug. 28 | 154 | 21.76 | July 27 | 610 | 18.60 | Sept. 2 | 152 | 20.32 | Aug. 8 | 0 | 41.54 | Aug. 8 | 0 | 44.15 |
| 20 | Aug. 22 | 0 | 19.59 | Sept. 4 | 0 | 32.40 | July 31 | 307 | 19.75 | Sept. 4 | 0 | 31.12 | — | — | 41.4† | — | — | 43.7† |
| 21 | — | — | 19.6† | — | — | 32.6† | Aug. 10 | 153 | 22.49 | — | — | 30.5† | — | — | — | — | — | — |
| 22 | — | — | — | — | — | — | Aug. 22 | 0 | 36.75 | — | — | — | — | — | — | — | — | — |
| 23 | — | — | — | — | — | — | Aug. 26 | 152 | 24.17 | — | — | — | — | — | — | — | — | — |
| 24 | — | — | — | — | — | — | Aug. 30 | 306 | 21.54 | — | — | — | — | — | — | — | — | — |
| 25 | — | — | — | — | — | — | Sept. 3 | 776 | 19.02 | — | — | — | — | — | — | — | — | — |
| | | | | | | | | | 18.6† | | | | | | | | | |

*Soil moisture tension is expressed in cm of water. Pw is grams of water per 100 grams of dry soil.
†Check value of Pw determined by drying at the termination of the experiment.

ment are given in the first row of data in Table 1. The successive dates for the successive equilibria are also given. In many cases the pots were allowed to stand longer than was necessary to attain equilibrium, but from intermediate gross pot weight readings it was made certain that equilibrium was attained before the tension

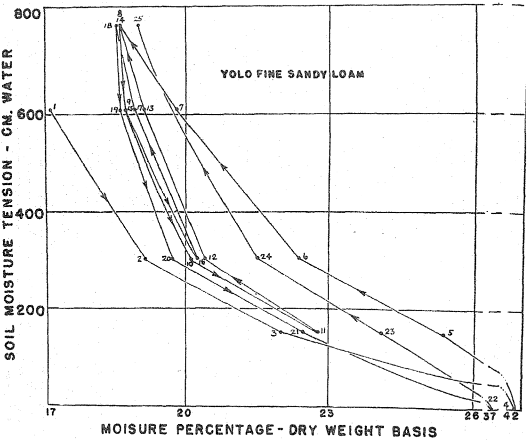


FIG. 4.—Curves showing equilibrium moisture sorption data for Yolo fine sandy loam. The numbers on the curves indicate the chronological order in which the various equilibria were obtained.

changed.[6] At the end of the experiment the moisture percentage was determined by drying as a check against the value calculated from the gross pot weight. These check values are given at the bottom of the moisture percentage columns. The soil moisture tension is given as the distance from the center of the soil mass (approximately 2.5 kilos) to the free water surface in the supply reservoir. This distance seldom varied more than ± 2 cm from the desired value.[7]

[6]It will be noted that for equilibria following 9 and 17 for the Indio soil, a decrease in tension resulted in a decrease in the moisture content. This is inconsistant with all past data and throws some doubt on whether points 9 and 17 were actually equilibria points.

[7]Table 1 gives the average moisture content and the average soil moisture tension in the soil mass, but because of the height of the soil column (18 cm) there is a tension difference at each equilibrium of 18 cm of water between the top and bottom of the column and at low tensions this results in a very appreciable moisture content gradient. Small changes in the level of the water in the supply reservoir at the zero tension setting produce corresponding changes in the water table in the soil pot with consequent large changes in the calculated (average) moisture percentage. This fact accounts in large part for the spread in moisture content values at zero tension.

As has been indicated by Haines (2) and by S. J. Richards (3) for sands, it is apparent from Fig. 4 that equilibrium between soil moisture tension and moisture content can be attained at any point within the hysteresis loop. Thus, any method for estimating soil moisture content that is based on a soil moisture tension measurement will involve an uncertainty as large as the width of the hysteresis loop, unless something is known of the moisture history of the soil. However, the amount of hysteresis found for the soils in Table 1 is probably considerably larger than occurs for these soils under field conditions. It is not known, for instance, to what extent the difference between the initial and subsequent wetting curves is due to the structural change occurring during the first wetting. Also, field experience and the time required to obtain the first three equilibrium points for the soils in Table 1 indicate that seldom is any appreciable fraction of the soil profile in the moisture states represented by the left hand curve in Fig. 4. On the other side of the hysteresis loop it will be noted from the data in Table 1 that the extreme curve is usually connected with the highest moisture content attained in wetting. Field experience with tensiometers indicates that seldom are well-drained soils beneath the surface few inches wetted to zero tension, even under basin irrigation. A hysteresis loop such as represented by points 9, 10, 11, 12, and 13 is more commonly to be expected in the field. Furthermore, as indicated by the data in Fig. 3, if the soil moisture is replenished with an ample application of water, the wetted part of the profile will exist in moisture states represented by drying (desorption or moisture retention) curves most of the time. For the extreme case, when the soil moisture fluctuates between fixed limits, the moisture regime will be represented by a single drying curve.

Little information seems to be available on hysteresis effects in porous media having fixed structure. Our experiments indicate, as would be expected, that the effect does exist and it appears that this should be an advantage rather than a disadvantage in the operation of sorption-block moisture meters. Hysteresis in the block will be in the same phase as hysteresis in the soil and hence will make the block weight more nearly correspond to soil moisture content.

## DISCUSSION

At equilibrium the soil moisture tension in a sorption block approaches equality with the tension in the contiguous soil. For agricultural purposes the most useful information that can be obtained from readings with a sorption-block soil moisture meter would be (a) an indication of the rate and time of approach to the wilting condition, and (b) an indication of the amount of available moisture present in the soil, expressed either as volume of water per unit depth of soil or as a fraction of the available range for the soil.

Recent experiments at this laboratory (5, 6) indicate that the first of these objectives can be achieved with sorption blocks. Readings for a series of sorption-block installations can be quickly interpreted if the blocks are tared so as to have the same weight at the wilting

condition. To attain the second objective may require the selection of sorption blocks with a moisture retention characteristic related in a fairly definite way to the characteristic curve for the soil. This, however, should not be difficult to do.

When the U. S. Weather Bureau was first established to obtain information of use to farmers, the moisture reserve in the soil was proposed as one element in the crop environment to be widely measured and reported. The difficulties encountered did not make this feasible. For such purposes as crop yield forecast, a representative indication of moisture reserves available in the soil for maturing a crop would be useful and the sorption block moisture meter may prove suitable for this kind of work. A more immediate and practical application, of course, would be its use as an aid in soil moisture control under irrigation.

As Davis and Slater (1) have indicated, the sorption-block type of moisture meter makes possible the "sequent measurement" of moisture changes at a given location which is of particular advantage in following continuously the depletion of available moisture. When properly built, these units should require little servicing or attention and accurate results should be immediately obtainable even with long periods of neglect or elapsed time between readings. The units are not susceptible to frost injury or to disturbances from salt effects in soils. This latter feature is of considerable importance to the work of the Salinity Laboratory where the moisture regime of plants in saline and alkali soils is under study. The authors are inclined to favor ceramic sorption blocks, thus avoiding troubles that may arise from the solubility and low mechanical strength of gypsum.

The temperature of the sorption block, as well as the temperature of the adjacent chamber and soil, should be representative of the surrounding soil so as to prevent condensation in the sorption block chamber and to prevent moisture gradients in the soil adjacent to the block which might arise in response to temperature disturbances introduced by the tube. We have used steel tubing in our units. This may be expected to give trouble with shallow installations, especially where the temperature of the exposed part of the tube differs considerably from the soil temperature. We have not made a careful study of temperature disturbances, but for installations at a depth of 6 inches in greenhouse pots (Fig. 3), data for morning and evening readings lie on a smooth curve.

Experiments should be conducted to determine the characteristics of porous ceramic material best suited for sorption block use and to determine more precisely what correspondence there is between block weight and soil moisture content for various wetting and drying rates and limits. We have used the pressure-membrane apparatus for obtaining the moisture retention curves for various porous ceramic materials, but this work has not proceeded far enough to make specific recommendations. It appears that a reasonably satisfactory test of the relation between sorption block weight and moisture content can be made in soil pots containing a uniformly distributed plant root system. Under proper conditions the moisture

throughout the pot is depleted fairly uniformly and the soil moisture content at the block can be inferred from the gross pot weight.

## SUMMARY

A porous ceramic block if protected from evaporation will come to moisture equilibrium with soil with which it is in contact. A description is given for a sorption-block soil moisture meter based on weighing the block while suspended in the soil, thus avoiding exposure to evaporation. Various tests made indicate that this type of apparatus can be used for measuring the condition and amount of moisture in soil.

Data on the hysteresis effect for six soils are given. The occurrence of hysteresis in ceramic sorption blocks is noted, and this, being in phase with that of the soil, should improve their action for measuring soil moisture.

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# MINOR ELEMENT STUDIES WITH SOYBEANS: I. VARIETAL REACTION TO CONCENTRATIONS OF ZINC IN EXCESS OF THE NUTRITIONAL REQUIREMENT[1]

E. B. EARLEY[2]

THERE is usually considerable variation among plant varieties of a given species in reaction to temperature (6, 8, 10, 15),[3] drought (5, 16), disease (1, 9, 19), insects (3, 12, 13, 17), etc. It is likewise known that plant varieties react differently in the absorption and metabolism of at least some of the chemical elements. Such varietal differences have been noted by Anderson and Ayre (2), Burkholder and McVeigh (4), and Hoener and DeTurk (11) for nitrogen; by DeTurk, *et al.* (7), Lyness (14), and Smith (18) for phosphorus; by Weiss (20) for iron, and by Allen[4] for several of the major elements. Yamasaki (21) observed the differential behavior of rice and wheat varieties to copper sulfate, sodium arsenate, zinc chloride, mercuric chloride, potassium dichromate, potassium cyanide, potassium perchlorate, potassium iodate, potassium bromate, and potassium and sodium chlorate. From his experiments, he concluded that definite varietal distinctions existed only with respect to the chlorates and that the basis for this distinction is the differential ability of the plants to reduce the nontoxic chlorate ions to the toxic hypochlorite ions.

With reference to the effect of the other chemicals tested for varietal reaction, Yamasaki (21) stated that, "All of the salts tested other than the chlorates, $KClO_3$ and $NaClO_3$, injured the seedlings very seriously as a whole but never showed the varietal distinctions as observed in relation to $KClO_3$." This statement is believed by the writer to be unjustified on the basis that Yamasaki correlated the results of an experimentally determined concentration of $KClO_3$ (0.2%) with those from an equal concentration of $ZnCl_2$, and concluded therefrom that the latter was incapable of inducing varietal distinction. Had he experimented as thoroughly with different concentrations of the other salts as he did with the chlorates, he probably would have discovered that varietal distinction to direct toxicants[5] is a matter of salt concentration rather than salt specificity.

The purpose of this paper, therefore, is to call attention to the

[1]A contribution of the former U. S. Regional Soybean Industrial Products Laboratory, Urbana, Ill., a cooperative organization participated in by the U. S. Dept. of Agriculture and the agricultural experiment stations of the North Central States of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin. Received for publication May 1, 1943.

[2]Assistant Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Dept. of Agriculture.

[3]Figures in parenthesis refer to "Literature Cited", p. 1022.

[4]ALLEN, DENVER I. Differential growth response of certain varieties of soybeans to varied mineral nutrient conditions. Unpublished doctor's thesis, University of Missouri. 1941. Copy on file Department of Agronomy, University of Missouri, Columbia, Mo.

[5]Those salts whose toxicity to plants is independent of chemical change are termed direct toxicants.

varietal reaction of soybeans to zinc and to show the magnitude of the difference between the most susceptible and resistant varieties studied.

## EXPERIMENTAL RESULTS

The effect of zinc on the growth of soybean plants was observed in the greenhouse during the fall of 1937. At that time an alloy pump, later found to be 95% zinc, was used to pump the nutrient solution into crushed quartz in which the plants were growing. The composition of the nutrient solution in which the zinc toxicity symptoms first appeared was as follows:

| Elements | N | P | K | Mg | Ca | S |
|---|---|---|---|---|---|---|
| Parts per million | 84 | 62 | 156 | 48 | 120 | 64 |
| Millimoles | 6 | 2 | 4 | 2 | 3 | 2 |

| Salts | Moles |
|---|---|
| $KH_2PO_4$ | .002 |
| $KNO_3$ | .002 |
| $Ca(NO_3)_2 \cdot 4H_2O$ | .002 |
| $CaCl_2 \cdot 2H_2O$ | .001 |
| $MgSO_4 \cdot 7H_2O$ | .002 |

Also 0.06 p.p.m. of Cu as $CuSO_4 \cdot 5H_2O$; 0.5 p.p.m. of B as $H_3BO_3$; 0.5 p.p.m. of Mn as $MnCl_2 \cdot 4H_2O$ and 2.0 p.p.m. of iron as $FePO_4 \cdot 2H_2O$

When about 3 weeks old, the plants developed symptoms similar to those shown in Fig. 1. These symptoms, in approximate order of appearance, consisted in the incipient formation of a red pigment at the base of the central leaf vein, the curling under of the leaves, chlorosis of the trifoliate leaves near the growing point of the stem, a dying of the apex of the stem, and an intensification of the red pigment in the leaf veins, petiole, and stem. A slight increase of manganese and boron as well as the addition of iron as ferric chloride did not alleviate the condition of the plants, whereas an increased pH brought about considerable improvement.

### COMPARATIVE EFFECT OF ZINC NITRATE AND DISSOLVED ZINC-ALLOY PUMP ON GROWTH OF HUDSON MANCHU

From the results of the above experiment it was hypothesized that enough zinc was being dissolved from the zinc-alloy pump to injure the plants. This idea was tested by making a dilute hydrochloric acid solution of the pump, of known concentration, and comparing its effect upon plant growth with that of an equal concentration of zinc nitrate solution. In this experiment seven bottles were used, each containing 18 liters of a standard nutrient solution. These consisted of a check bottle receiving no zinc and two sets of three bottles each, with one set receiving 1, 2, and 4 p.p.m. of zinc as alloy pump and the other set receiving the same concentrations of zinc as zinc nitrate. Each bottle supported four plants, two Hudson Manchu and two Peking.

Identical symptoms were produced in the plants by the two solutions. This fact, therefore, confirmed the above hypothesis that zinc from the nutrient solution pump caused the death of the soybean plants. The photographs in Figs. 2 and 3 show the similarity of reaction of Hudson Manchu plants to zinc from these two sources.

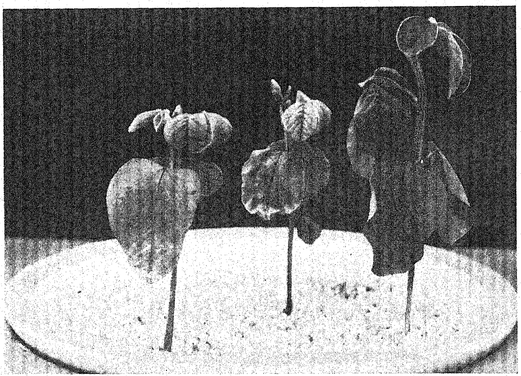

FIG. 1.—Boone plants exhibiting typical zinc toxicity symptoms. They were produced as the result of burying one-half of a zinc alloy pump in the crushed quartz. Planted April 23, 1938; photographed June 7, 1938.

The effect of zinc from the alloy pump casting and of zinc nitrate on root formation of the Hudson Manchu variety may also be observed in Fig. 4. As much as 1 p.p.m. of zinc in either of the above forms appeared to have no harmful influence on root development, whereas 2 and 4 p.p.m. of zinc inhibited growth very seriously.

## VARIETAL REACTION TO ZINC

It was noted in this work that soybean varieties differed greatly in their toleration of an equal concentration of zinc in the nutrient solution. Of the four varieties being studied at this time, Mandarin, Mandell, Illini, and Boone, Mandarin showed the greatest tolerance and Boone the least.

To determine further the varietal reaction of soybeans to zinc, gravel boxes A and B were each planted to eight varieties of four plants each on April 18, 1938. For box A (Fig. 5) the pH of nutrient solution on April 22, 26, and May 2 was 6.0, 6.5, and 6.9 respectively. Box B (Fig. 6) remained at pH 7.0 throughout the test. The day temperature of the greenhouse ranged from about 70° to 85° F and the night temperature ranged from about 50° to 65° F.

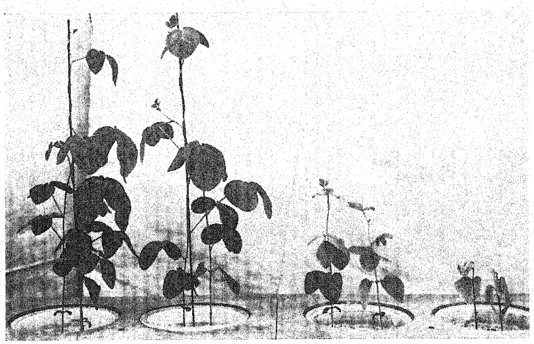

FIG. 2.—The effect of increasing the amount of zinc as zinc nitrate in the nutrient solution upon the growth of Hudson Manchu soybeans in crushed quartz. Planted October 20, 1938; photographed November 28, 1938.

The zinc concentration of these solutions was unknown; however, the results of later tests with Hudson Manchu and Peking indicated a concentration of about 0.3 p.p.m. and 2.3 mgms per plant.

FIG. 3.—The effect of increasing the amount of zinc as dissolved nutrient-solution-pump in the nutrient solution upon the growth of Hudson Manchu soybeans in crushed quartz. Planted October 20, 1938; photographed November 28, 1938.

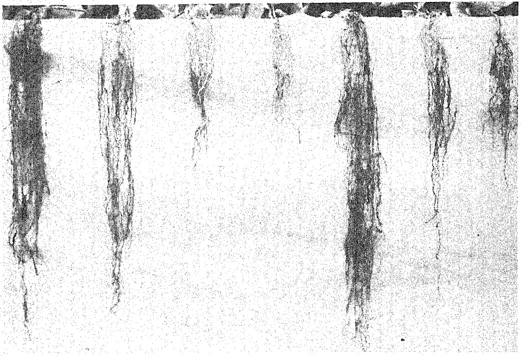

FIG. 4.—Effect of zinc on root growth of Hudson Manchu soybeans. Left to right: Check, 1 p.p.m., 2 p.p.m., and 4 p.p.m. of zinc as alloy pump, and 1 p.p.m., 2 p.p.m., and 4 p.p.m. of zinc as zinc nitrate. Planted October 20, 1938; photographed November 28, 1938.

The results of this experiment showed the order of the eight varieties in each box, based on increasing susceptibility to zinc, to be as follows:

| Box A (Fig. 5) | Box B (Fig. 6) |
|---|---|
| {Hudson Manchu, Biloxi}* | Giant Green |
| {Mandarin, Habaro} | {Mandarin, Mandell} |
| Harbinsoy | Mukden |
| {Scioto, Morse} | Virginia |
| | Dunfield-B |
| Boone | Boone |
| | Peking |

*The varieties in brackets appeared to gi e the same reaction.

In the front rows of box B (Fig. 6), Peking and Boone occur in adjacent rows and it may be observed that the former is more susceptible to zinc than the latter. It was also seen in boxes A and B (Figs. 5 and 6) that Hudson, Manchu, Biloxi, and Giant Green can successfully tolerate a higher concentration of zinc than Mandarin. So, among the additional varieties studied, Hudson Manchu was found to show a higher tolerance to zinc than Mandarin, and Peking to be more susceptible than Boone.

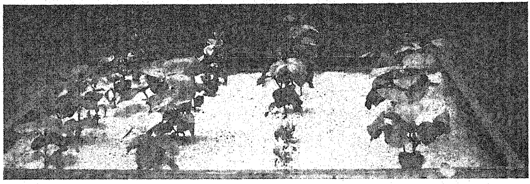

FIG. 5.—Box A, varietal reaction of soybeans to zinc in a nutrient solution with a slightly acid reaction. The varieties are, left to right back rows, Scioto, Morse, Mandarin, and Harbinsoy; front rows, Habaro, Hudson Manchu, Boone, and Biloxi. Planted April 18, 1938; photographed May 24, 1938.

These tests revealed that varieties of soybeans exhibit striking variations in reaction to a zinc concentration of approximately 0.3 p.p.m. in a slightly acid or neutral nutrient solution. The degree of damage from zinc may be said to increase with decreasing pH. Boone, growing in boxes A and B (Figs. 5 and 6), illustrates this point very nicely. In box A, with a slightly acid nutrient solution, this variety is severely damaged, while in box B, with a neutral nutrient solution, it shows only slight damage.

## MAGNITUDE OF VARIETAL REACTION TO ZINC

The varietal difference between Hudson Manchu and Peking appears to represent the extremes in reaction to zinc, with the former

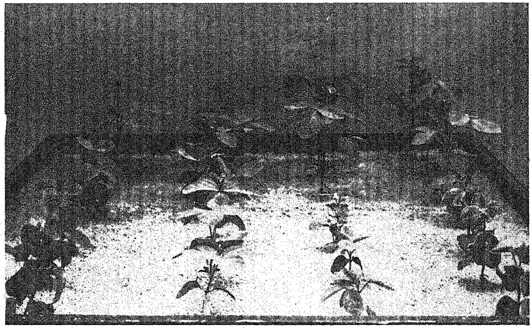

FIG. 6.—Box B, varietal reaction of soybeans to zinc in a nutrient solution with a pH of 7.0. The varieties are, left to right back rows, Virginia, Mandell, Giant Green, and Mandarin; front rows, Dunfield-B, Mukden, Peking, and Boone. Planted April 18, 1938; photographed May 24, 1938.

evidencing no deleterious effects from a concentration of zinc that killed the latter. These two varieties, therefore, were selected for the purpose of measuring quantitatively the difference in tolerance to zinc. An experiment was set up in which zinc nitrate was used as the source of this element.

Fourteen 2-gallon, glazed, earthenware jars filled with acid-washed crushed quartz and connected to seven pyrex bottles, each containing 18 liters of nutrient solution, constituted the apparatus. The composition of the nutrient solution used in the pot tests is given below;

| Elements | N | P | K | Mg | Ca | S |
|---|---|---|---|---|---|---|
| Parts per million | 140 | 62 | 234 | 97 | 200 | 192 |
| Millimoles | 10 | 2 | 6 | 4 | 5 | 6 |

| Salts | Moles |
|---|---|
| $KH_2PO_4$ | .002 |
| $KNO_3$ | .004 |
| $Ca(NO_3)_2 \cdot 4H_2O$ | .003 |
| $CaSO_4 \cdot 2H_2O$ | .002 |
| $MgSO_4 \cdot 7H_2O$ | .004 |

Also 0.5 p.p.m. of Mn as $MnCl_2 \cdot 4H_2O$, 0.2 p.p.m. of B as $H_3BO_3$ crystals, and iron as $FeCl_3 \cdot 6H_2O$ added to gravel when needed.

Each bottle was connected to two jars. In one of the two jars, two Hudson Manchu plants were grown and in the other jar two Peking plants. The concentration of zinc in the seven bottles was as follows: Bottle 1, check; bottle 2, 0.1 p.p.m.; bottle 3, 0.2 p.p.m.; bottle 4, 0.4 p.p.m.; bottle 5, 0.8 p.p.m.; bottle 6, 1.6 p.p.m., and bottle 7, 3.2 p.p.m. Bottles 1 to 7, therefore, contained no zinc, 1.8, 3.6, 7.2, 14.4, 28.8, and 57.6 mgms, respectively. Since each bottle received only the initial quantity of zinc during the experiment and since each supported four plants, the amount of zinc per plant for bottles 1 to 7 was none, 0.45, 0.9, 1.8, 3.6, 7.2, and 14.4 mgms, respectively. The experiment was started February 17, 1939, and the plants photographed May 19, 1939. Distilled water was used in making the nutrient solutions and in maintaining the volume during the course of the experiment. The solution was forced into the gravel by means of air pressure four times daily.

Under the conditions of this test it was found that Peking successfully tolerated a zinc concentration of 0.1 p.p.m. (0.45 mgms per plant) and Hudson Manchu successfully tolerated a zinc concentration of 0.8 p.p.m. (3.6 mgms per plant). It may be observed from Fig. 7 that Peking was damaged at 0.2 p.p.m. (0.9 mgms per plant) and completely destroyed at 0.4 p.p.m. of zinc (1.8 mgms per plant). Hudson Manchu (Fig. 8), on the other hand, while unaffected by 0.8 p.p.m. of zinc (3.6 mgms per plant) was killed by 1.6 p.p.m. (7.2 mgms per plant). It may be conjectured that about 1.2 p.p.m. of zinc (5.4 mgms per plant) is very close to the maximum concentration which Hudson Manchu can tolerate with little or no apparent ill effects. This statement is partially substantiated by the normal

FIG. 7.—The effect of zinc as zinc nitrate upon the growth of Peking soybeans when produced in crushed quartz with nutrient solution. The zinc treatments, left to right, were: Check, 0.1 p.p.m., 0.2 p.p.m., and 0.4 p.p.m. Planted February 17, 1939; photographed May 19, 1939.

growth of Hudson Manchu at a concentration of 1 p.p.m. (4.5 mgms per plant) of zinc shown in Fig. 2.

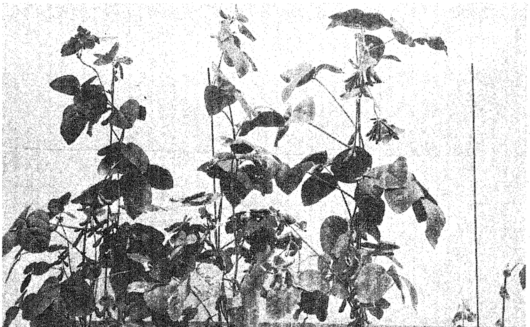

FIG. 8.—Effect of zinc as zinc nitrate upon the growth of Hudson Manchu when raised in crushed quartz with nutrient solution. The zinc treatments, from left to right, were: Check, 0.4 p.p.m., 0.8 p.p.m., and 1.6 p.p.m. Planted February 17, 1939; photographed May 19, 1939.

## DISCUSSION

The reason why soybean varieties react differently to the same external concentration of zinc was not established in this work. However, since zinc is considered a direct toxicant, that is, requiring no oxidation-reduction reaction to convert it into a toxic form as is true of the chlorates, it may be assumed that varietal reaction is due either to differential absorption or differential tolerance, or to the interactivity of these two processes.

The apparent operation of the former of these two phenomena was observed by Hoener and De Turk (11) in their investigation of the nitrogen metabolism of Illinois high and low protein strains of corn. They state that, "The differential absorption of nitrates suggests the possibility of a 'resistance mechanism' to absorption. This resistance is lower in the high protein strain, being overcome by an external concentration of 100 p.p.m., of nitrate at which concentration abundant intake occurs. But in the low protein strain the resistance is much greater, being above 100 p.p.m., since it was only in the 200-p.p.m., culture that nitrate absorption occurred in more than minimal quantity."

The work of Yamasaki (21) also supports the view that there exists differential absorption among plant varieties for the chlorate ion. However, as stated elsewhere, he found that varietal distinction to $KClO_3$ was not due to differential absorption or tolerance but rather to differential ability of the varieties to reduce $KClO_3$ to hypochlorites. Apparently all varieties absorbed sufficient $KClO_3$ to cause their death had the salt been completely reduced to the toxic hypochlorite ion.

The functioning of "differential tolerance" of plant varieties to the same percentage concentration of elements within their tissue likewise has been noted. The work of Allen[6] shows that, whereas Virginia and Morse soybeans contained 2.9% potassium, respectively, when grown in nutrient solution containing 4 millimoles of potassium, the Morse tolerated this concentration more favorably than Virginia, as indicated by the dry weight data. These same varieties also when grown with 5 millimoles of phosphorus revealed that Morse tolerated this concentration to a more favorable extent than did Virginia. No chemical analysis of these plants were given; however, they were probably very similar at the time differential tolerance started to be manifested.

The soybean plants in this experiment were not analyzed for zinc because they were carried beyond the proper sampling period for final observation and photographing. Consequently, it is not known whether varietal distinction was effected by differential absorption or differential tolerance or by the interactivity of the two processes. However, the writer believed it worthwhile to illustrate these processes diagrammatically, on the basis of observed varietal reaction to zinc, for the purpose of clarifying the concept of each. Fig. 9 illustrates differential absorption and the interactivity of differential absorption and differential tolerance. The upper curve for Peking

[6]*Loc. cit.*

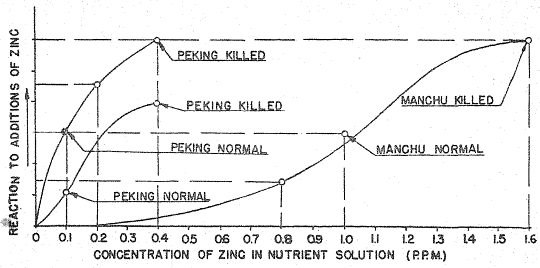


Fig. 9.—An illustration of differential absorption and the interactivity of differential absorption and differential tolerance of zinc by Peking and Hudson Manchu.

and the Manchu curve illustrate possible differential absorption since at 0.4 p.p.m. of zinc, for instance, Peking absorbed its lethal concentration of zinc whereas Manchu obviously did not. The lower Peking curve and the Manchu curve illustrate interactivity of the two processes in that both of these were operative in producing varietal distinction. For example, Peking not only possibly absorbed zinc at a faster rate than Manchu (differential absorption) but also was killed by a lower percentage concentration of zinc than Manchu (differential tolerance). Fig. 10 illustrates differential tolerance where both varieties possibly absorbed zinc at a correspondingly similar rate at each external concentration, until the resulting percentage of zinc in the tissue killed one variety (Peking) without apparent harm to the other variety (Manchu).

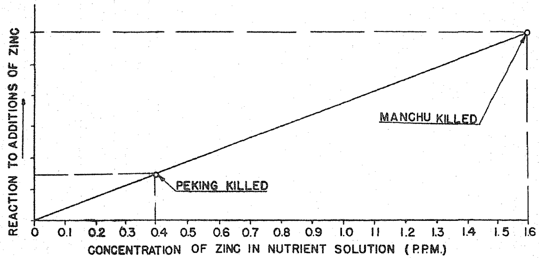


Fig. 10—An illustration of differential tolerance of zinc by Peking and Hudson Manchu.

## CONCLUSIONS

The deleterious substance responsible for the death of the soybean plants attempted to be grown in the greenhouse during the fall of 1937 and spring of 1938 was zinc which had dissolved from the nutrient solution pump.

There exists a distinct varietal variation among soybeans in reaction to approximately 0.3 p.p.m. (2.3 mgms per plant) of zinc in a slightly acid nutrient solution when plants are grown in crushed quartz.

Hudson Manchu will successfully tolerate 8 and perhaps 12 times the external concentration of zinc as will Peking.

The mechanism of varietal reactions of soybeans to zinc was not determined, although differential absorption and tolerance are discussed in this connection.

The reaction of soybean varieties to zinc showed no correlation to percentage of oil or protein of the seed. Likewise, there appeared to be no consistant relationship between color of seed and plant reaction to zinc. Among the varieties studied, with the exception of Biloxi and Virginia, early maturity and resistance and late maturity and susceptibility appear to be associated. Also, with regard to size of seed and varietal reaction to zinc, it may be stated that the most resistant varieties were the largest seeded ones, while the most susceptible varieties were the smallest seeded ones.

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# NOTES

## THE USE OF THE NITROGEN ISOTOPE $N^{15}$ IN DETERMINING NITROGEN RECOVERY FROM PLANT MATERIALS DECOMPOSING IN SOIL[1]

MANY practical agronomic problems center round the availability and recovery of the nitrogen of crop residues. The nitrogen transformations that occur when plant materials are incorporated in the soil are complex, though the general principles underlying them have probably been established. Studies in this field, however, will acquire a greater degree of precision and certainty when the nitrogen isotope of mass 15 is used as a tracer. This isotope can now be obtained in the form of ammonium nitrate, the ammonium ion of which is enriched very substantially above the normal figure of 0.38 atom %. Enriched nitrate can, however, be prepared by distilling off the ammonia and submitting it to biological oxidation in a percolating filter in which an active nitrifying population has been developed. If organic sources of nitrogen containing the isotope are desired they can be obtained by supplying an appropriate plant with an enriched ammonium or nitrate salt. With these three forms available it will be possible to examine in detail the nitrogen changes involved in the decomposition of plant materials. The chemical properties of the isotope are, of course, identical with those of the normal form, so that it appears in the tissues of plants and microorganisms in the same proportion as in the source of nitrogen supplied.

Accurate figures for the quantity of nitrogen immobolized by low-nitrogen residues will be obtainable by adding an enriched inorganic source and following the distribution of the isotope in the organic form at intervals. Likewise, the rate and amount of

[1]Journal paper No. J-1151 of the Iowa Agricultural Experiment Station, Project 789, Iowa State College, Ames, Iowa.

nitrogen liberated in the inorganic form from plant materials containing nitrogen in excess of that needed for microbial synthesis during decomposition in soil will be determinable accurately if the protein of the plant materials concerned contains a known amount of the isotope. Knowledge of the percentage of $N^{15}$ in the nitrogen released from the plant material permits the calculation of the amount of nitrogen derived from that source, even though it is diluted by that concurrently becoming available from the soil organic matter, because the latter contains only the normal abundance.

In the course of some studies on the effect of inorganic nitrogen on the amount of nitrogen fixed by soybeans, which will be reported elsewhere, the opportunity was taken to test the procedure just described. Fifty-gram samples of ground soybean plants were incorporated in 12 kilos of soil-sand mixture in 2-gallon pots. The N content of the plant material was 2.15%, and the $N^{15}$ present amounted to 0.684% of the N, or 0.304% in excess of normal. Soybean plants were grown on this mixture to near maturity (11 weeks, April 7 to June 24), and the tops and roots harvested for yield. Four replicate pots of inoculated and four of uninoculated beans were present in the experiment. After weighing, pairs of samples were combined for analysis. The relevant results are given in Table 1.

TABLE 1.—*Determination of N recovery from soybeans incorporated in a soil-sand mixture.*

| Sample | Yield, grams | Mean | N content, % | N present, mg | $N^{15}$ content, % of N | $N^{15}$ present, mg | $N^{15}$ from normal, mg | $N^{15}$ excess, mg | N from soybean material, mg |
|---|---|---|---|---|---|---|---|---|---|
| | | | Uninoculated Soybeans | | | | | | |
| A | 45.4 | 47.0 | 1.94 | 912 | 0.474 | 4.323 | 3.465 | 0.858 | 282 |
| B | 48.5 | | | | | | | | |
| C | 53.7 | 49.6 | 1.86 | 923 | 0.466 | 4.301 | 3.507 | 0.794 | 261 |
| D | 45.4 | | | | | | | | |
| | | | Inoculated Soybeans | | | | | | |
| A | 71.6 | 77.0 | 2.79 | 2,148 | 0.420 | 9.022 | 8.162 | 0.860 | 283 |
| B | 82.4 | | | | | | | | |
| C | 65.8 | 66.5 | 2.87 | 1,909 | 0.430 | 8.209 | 7.254 | 0.955 | 314 |
| D | 67.2 | | | | | | | | |

Because the $N^{15}$ excess could only be derived from the nitrogen which became available from the plant material as it decomposed, it is possible to calculate the amount of the latter. This is the figure in the last column, which is obtained by dividing the amount of $N^{15}$ excess in the plants by 0.304, the percentage excess in the soybean material incorporated in the soil. Although the nodulated soybean plants had an additional source of nitrogen, namely, that obtained by fixation from the air, the same calculation is applicable because atmospheric nitrogen also contains the normal abundance of $N^{15}$. It is possible that the uptake of nitrogen by the nodulated plants might be different to that by unnodulated plants; but the data here

are insufficient to answer this point. Taking the mean of all pots, it appears that 285 mg of N out of the 1,075 mg present in the soybean material incorporated became available and was taken up by the crop in 11 weeks, a recovery of 26.5%.

It will be noted that this answer is arrived at without the use of data from pots not receiving additions of the soybean material. In the past, reliance has had to be placed on differences in yield and nitrogen content between plants grown with and without the addition of the plant material in question, and the assumption made that the nitrogen derived from the soil organic matter is equal in both cases. This assumption is questionable and under some circumstances may be quite incorrect for two reasons, *viz.*, (1) if there is a great disparity between the root systems in the treated and untreated pots, the uptake of soil-derived nitrogen may be of a different order; and (2) the amount of nitrogen becoming available from the soil organic matter may be increased or decreased by the added plant material. These uncertainties are avoided by the use of the procedure suggested.

These data are presented, not because they have special intrinsic value, but as illustrative of the use of isotopic nitrogen as an aid in decomposition studies of this type.—A. G. NORMAN, *Soils Subsection, and* C. H. WERKMAN, *Bacteriology Section, Iowa Agricultural Experiment Station, Ames, Iowa.*

## THE RAPID GERMINATION OF A SPECIES WITH A MUCILAGINOUS SEED COAT, *PLANTAGO FASTIGIATA* MORRIS

THE germination of the seed of *Plantago fastigiata*, a native winter annual, was investigated by Barton in 1936.[1] She obtained a germination of 27% at 20° C after storage for 9 months and suggested no other method of overcoming dormancy. The period after maturity in the spring is spent on the ground with germination occurring in the fall.

In 1941, a sample of this plantain, No. S-30,831, was received for test from Tucson, Ariz. The plantains are valued in the southwest where they furnish considerable winter and early spring grazing.

The seed had been harvested in April, 1941, and when tested in July after stratification in moist soil for 1 month, a method found beneficial for many lots of newly harvested seeds, this sample germinated 3.5% during a total incubation period of 4 months.

The mucilaginous layer surrounding the seed swelled considerably upon contact with water and appeared to be the probable cause of dormancy. Two simple methods of removing this layer were tried.

In September, 1941, 200 seeds were soaked 48 hours in water and then dried. The resulting coherent mass was broken up by hand pressure whereby much of the mucilaginous matter was reduced to flakes and removed from the surface of the seeds. A germination of 65.5% was obtained after 2 months' incubation on toweling in petri dishes at daily alternating temperatures of 15° to 32° C with light.

[1]BARTON, LELA V. Germination of desert seeds. Contr. Boyce Thompson Inst., 8:7–11. 1936.

21.5% dormant seeds still remained. Tests made simultaneously, without presoaking, on soil in petri dishes at the above daily temperature alternation, at 17° C, and at 10° C yielded 5.5%, 1.5% and 0% germination, respectively, within the 2 months.

These results were not entirely satisfactory because of the large amount of apparently sound ungerminated seed remaining, and a second method was therefore tried. Dry, finely divided peat was added to the soaked seed for the purpose of adsorbing the mucilage and the mass permitted to dry thoroughly before breaking it up. This treatment was suggested by a method used commercially in removing seeds of buckhorn plantain, *Plantago lanceolata* L., from red clover by means of moist sawdust.

In a test made in October, 1941, 200 seeds were soaked in water for 48 hours, then mixed with dry peat (Table 1). The mass, when thoroughly dry, was broken up as much as possible without injuring the seeds and the material incubated at 15° C for 17 hours and approximately 32° for 7 hours daily with light on soil in petri dishes. In 18 days 52.5% germination had occurred and in 28 days, 65%. When tests were transferred to a constant temperature of 17° C, 19% additional seedlings occurred, raising the figure to 84% over a total of 49 days. Although no unsoaked tests were made at this time, tests of 400 unsoaked seeds made in January, 1942, yielded only 19% seedlings at 17° C and 11% seedlings at 15° to 32° C daily alternation. There were indications from other incompleted tests that a much shorter period of soaking (3 hours) might be sufficient.

TABLE 1.—*Germination of the seed of Plantago fastigiata by removal of the mucilaginous outer layer of the seed coat.*

| Date of test | Pre-treatment | Germination temperature, ° C | Germination % | Duration of test, days |
|---|---|---|---|---|
| | | 1941 | | |
| July 26 | Stratified at 5°C, 1 month | 15°–32°* | 3.5 | 120 |
| Sept. 10 | None | 17° | 1.5 | 56 |
| Sept. 10 | None | 10° | 0.0 | 56 |
| Sept. 13 | None | 15°–32°* | 5.5 | 53 |
| Sept. 13 | Soaked 48 hours, then dried† | 15–32°* | 65.5 | 53 |
| Oct. 27 | Soaked 48 hours, then mixed with dry peat and dried† | 15°–32°* then to 17° | 65.0<br>84.0‡ | 28<br>49 |
| | | 1942 | | |
| Jan. 14 | None | 17° | 19.0 | 21 |
| Jan. 14 | None | 15°–32°* | 11.0 | 21 |

*15° C for 17 hours and approximately 32° C for 7 hours daily with light.
†The mass then broken up as nearly as possible to individual seeds.
‡81.5% in 31 days.

It is believed that soaking and thoroughly drying, with or without a dry material such as peat, and the subsequent removal of the

mucilaginous particles by mechanically breaking down the material as much as possible to the individual seeds before sowing, probably by means of a hammer mill, could be applied to the large-scale plantings of mucilaginous seeds such as those of the plantains.—M. P. MAULDIN, *Soil Conservation Service Seed Laboratory, San Antonio, Texas.*

# FELLOWS ELECT FOR 1943*

## THOMAS RAY STANTON

THE first Fellow to be presented to the Society was born in Grantsville, Md., September 23, 1885. He received his college training at the University of Maryland, graduating in 1910; and received his Master's degree in 1921. Since 1911 he has served with the U. S. Dept. of Agriculture and has been in charge of oat investigations since 1916.

In his service for the Department he has been instrumental in initiating, directing, and helping to correlate throughout the United States one of the most successful jobs of plant breeding in this or any other country, namely, the development of new rust, smut, and cold resistant oat varieties now coming into extensive use. The value of this work was indicated in several papers given at this meeting.

Without detracting from the credit due many able men who made important contributions to the program, it is proper to say that this man through his vision, perseverance, long service, and cooperative spirit has made a fine contribution to agronomy and to his country—THOMAS RAY STANTON.

## FRANK LESLIE DULEY

THE next Fellow is one of those thorough, careful, and painstaking scientists who have contributed so much to the development of improved agronomic practices.

DOCTOR FRANK LESLIE DULEY was born in Grant City, Mo., December 21, 1888, and received his Bachelor's and Master's degrees at the University of Missouri. During the next ten years he was on the staff of the Missouri Agricultural Experiment Station, advancing from an Assistant to an Associate Professor. In this period, while on leave of absence, he completed his graduate work at the University of Wisconsin, receiving his doctorate in 1923. From 1925 to 1933 he was Professor of Soils at Kansas State Agricultural College. Since 1933 he has served, with distinction, in the Soil Conservation Service.

Doctor Duley has worked in the field of soil fertility, plant nutrition, soil erosion control, and the conservation of soil moisture. He has served this Society and the Soil Science Society of America in many ways.

*Citations prepared by Dr. Frank W. Parker, Vice President of the Society.

## HORACE JAMES HARPER

THE third Fellow to be presented to the Society is one of our most versatile agronomists and soil scientists. He was born in Vinton, Iowa, February 14, 1896, and received his Bachelor's and Master's degrees at Iowa State College. Following graduation he served on the Experiment Station staff.

In 1923 he completed his doctorate work at the University of Wisconsin, and it was there that I had the pleasure of coming to know this genial and enthusiastic scientist, who has made notable contributions in soil chemistry, soil fertility, and soil morphology before and since he went to Oklahoma in 1925.

This man has served this Society in many capacities. He was President of the Soil Science Society in 1942; is a member of the American Chemical Society and the International Society of Soil Science. He is appreciated by his associates—HORACE JAMES HARPER.

## THOMAS BARKSDALE HUTCHESON

VIRGINIA is the "Mother of Presidents", but many Virginia farmers will tell you she has produced only one agronomist, PROFESSOR THOMAS BARKSDALE HUTCHESON.

Professor Hutcheson was born at Charlotte Court House, Va., in 1882. He graduated from the Virginia Polytechnic Institute in 1906 and received his Master's degree in 1908. With the exception of one year in Minnesota and another at Cornell, he has served Virginia continuously. Since 1914 he has been head of the Agronomy Department of Virginia Polytechnic Institute and Chief Agronomist of the Virginia Agricultural Experiment Station.

Professor Hutcheson is a farmer as well as an agronomist. He has operated a college farm of 2,000 acres for 20 years. With his brother he operates a 650-acre dairy farm and of course directs the work of the several substations of the Virginia Experiment Station. His versatility in the field of agronomy and agriculture is indicated by his monthly contributions to *Progressive Farmer* and frequent contributions to other farm papers. He is the most popular speaker before farm groups in Virginia and is a toastmaster *par excellence*. Professor Hutcheson is a great hunter and fancier, breeder, and trainer of dogs. Some of his dogs have won state honors in field trials.

Professor Hutcheson has been particularly active among southern agronomists, being a member of the Tobacco Research Committee and a regular attendant at the Association of Southern Agricultural Workers. He has been a member of this Society for many years and has served on many committees.

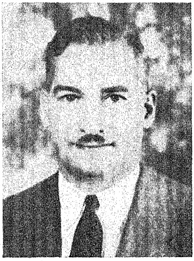
## WILLIAM BECK KEMP

Our next Fellow has had an unusual career in some respects. Like our first Fellow he is a native of Maryland and graduated from the University of Maryland in 1912. He then taught in a high school but soon went to West Virginia as Assistant Agronomist; returning after three years to Maryland as Extension Agronomist. His agronomic career was interrupted for a period of four years when he served as principal of a high school.

In 1921 he again became associated with the University of Maryland as Associate Agronomist, took his doctorate at American University in 1928, and has advanced to the head of the Department of Agronomy, and more recently has been Acting Director, of the Maryland Agricultural Experiment Station.

Doctor William Beck Kemp's scientific contributions have been in genetics, statistics, and more particularly in mathematical evaluation of biological data.

## NORMAN JAMES VOLK



The next Fellow to be presented this year has been a most fortunate individual, for like your Vice President he has had the privilege of working under both Emil Truog and Dean M. J. Funchess, as well as being closely associated with George Scarseth.

Norman James Volk was born in Oconto Falls, Wis., January 16, 1901. He graduated from the University of Wisconsin in 1923 and received his Master's degree the following year. After two years with the Texas Agricultural Experiment Station he became associated with the United Fruit Company from 1926 to 1936, but returned to Wisconsin for his Ph.D. in this period. Since 1936 he has been at the Alabama Agricultural Experiment Station and is now head of the Department of Agronomy.

Doctor Volk has worked on the nutrition and pathology of bananas, potash fixation, oxidation and reduction in soils, and in more recent years has given a great deal of attention to broad problems of soil fertility and fertilizer practices. Since his return from Central America he has been very active in the affairs of the Agronomy Society as well as the Soil Science Society.

# MINUTES OF THE THIRTY-SIXTH ANNUAL MEETING OF THE AMERICAN SOCIETY OF AGRONOMY

THE Thirty-sixth Annual Meeting of the American Society of Agronomy was held in the Netherland Plaza, Cincinnati, Ohio, November 10, 11, and 12. There were 422 members and guests registered in attendance.

The general meeting of the Society was held Thursday morning, November 11, with President F. D. Keim presiding. Dr. Elvin Frolik, University of Nebraska, presented a paper on "Seed Production of Improved Strains of Grasses and Legumes." Dr. W. V. Lambert, Associate Director, Purdue University, presented a paper on "Streamlining Projects to Meet Current Problems." Both papers were well received and will be published in the JOURNAL.

The annual dinner was held jointly with the Soil Science Society of America on Thursday evening. Dr. F. D. Keim gave the Presidential address entitled, "Agronomy and Human Beings" (pages 995 to 1001 in this issue of the JOURNAL). Howard M. Call spoke on "The Old Home Farm—One Hundred and Forty Years Ago and Now." His address will be published in the 1943 PROCEEDINGS of the Soil Science Society.

Vice President Frank W. Parker announced the Fellows Elect for 1943 and presented certificates to the following: Horace J. Harper, Thomas B. Hutcheson, Frank L. Duley, William B. Kemp, Thomas R. Stanton, and Norman J. Volk.

The Crops Section held two general sessions and 12 sectional meetings. The Soil Science Society held two general sessions and 13 sectional meetings. Two joint sessions were held. A total of 178 papers were presented during the meetings.

The Society voted to approve an amendment to the by-laws covering membership options as follows:

The annual dues for each active member for the Society shall be as follows:

| | |
|---|---|
| Option 1—Membership in the American Society of Agronomy and subscription to the JOURNAL | $5.00 |
| Option 2—Membership in the Soil Science Society of America and subscription to the PROCEEDINGS | $5.00 |
| Option 3—Membership in the American Society of Agronomy and Soil Science Society of America and subscription to the JOURNAL | $6.00 |
| Option 4—Membership in the American Society of Agronomy and Soil Science Society of America and subscription to the PROCEEDINGS | $6.00 |
| Option 5—Membership in the American Society of Agronomy and Soil Science Society of America and subscription to the JOURNAL and PROCEEDINGS | $9.00 |
| Option 6—Membership in the American Society of Agronomy (for undergraduate and graduate students only) | $1.00 |
| Option 7—Membership in the Soil Science Society of America (for undergraduate and graduate students only) | $1.00 |

A committee was approved to work in consultation with a committee from the Soil Science Society to secure greater cooperation with foreign scientists.

Reports by the Editor and Secretary-Treasurer and by the standing committees were presented and accepted and are appended hereto.

The Auditing Committee consisted of Dr. G. W. Conrey and Dr. A. T. Wiancko. The Nominating Committee consisted of President Keim, *Chairman*, Emil Truog, H. K. Hayes, M. A. McCall, and H. R. Smalley.

The Nominating Committee presented the name of H. D. Hughes for Vice President of the Society. Upon motion from the floor the Secretary was instructed to cast the ballot for the nominee and he was declared unanimously elected.

Respectfully submitted,
G. G. POHLMAN, *Secretary*.

## REPORTS OF OFFICERS AND COMMITTEES

### REPORT OF THE EDITOR

TAKING into account the complications of wartime with all their impact upon civilian activities and needs, we fared rather well in our publication requirements this past year. Just what 1944 holds for us, we shall not venture to predict. Sufficient unto the day are the rulings of the WPB, OPA, WMC, etc., etc.

Thus far, the JOURNAL has appeared very nearly on schedule and the reprints have been made available within a reasonable time. None of the printer's services are quite up to what we have been used to in the past, but due allowance must be made for the difficulties with which all private business must contend, especially with respect to shortage of labor and materials. I am satisfied that the printer will give the interests of the JOURNAL every consideration that circumstances permit.

Our most pressing immediate problem is that of paper. A ruling by the WPB on paper stocks for the last quarter of 1943, effective October 1st, made necessary a sharp revision in our publication schedule for the remainder of 1943 and means that Volume 35 will be at least 100 pages less than Volume 34. As a result the current volume will carry 107 articles as compared with 119 in 1942. In addition to the 107 articles, Volume 35 will contain 19 notes and 15 book reviews. Ten papers were deemed unsuitable or were withdrawn. As of October 25th, we have 22 papers on hand which have been approved for publication and 10 papers are in the hands of the Editorial Board. Of 20 papers returned to the authors for revision, several will doubtless be withdrawn or will be so completely revised as to constitute practically a new contribution upon their return. A total of 159 manuscripts had been received up to October 25th as compared with 169 for a similar period in 1942.

We are somewhat ahead of last year in the number of papers in reserve, including those approved for publication and those in the hands of reviewers or returned to the authors for revision. At this time the JOURNAL is made up through March 1944. Unless more stringent paper regulations are imposed, however, the publication schedule should not be further disrupted, and in fact, may improve slightly with time.

Since July 1st, we have been free of the censorship regulations which made it necessary that we obtain a special license from the Office of the Censor in order to mail the JOURNAL outside the United States and Canada. Even with this special license certain countries, including some South American countries, were closed to us. All of these limitations have now been removed, although we must, of course, observe the Code of Wartime Practices established by the Office of the Censor. These are commonsense regulations to prevent information of a vital nature reaching the enemy and have to do more with the reporting of the war news and of matters pertaining to war production, troop movements, etc., within this country than to the type of material that we publish in the JOURNAL.

Contrary to expectations, our advertising income has held up remarkably well through 1943, averaging well over a hundred dollars a month net. Early indications are that we shall be able to hold most of this through 1944.

The greatest satisfaction in the year's efforts, however, has been found in the fine relationships with contributors to the JOURNAL and with the Editorial Board. Naturally, there have been differences of opinion, but almost without exception the decisions of the Editorial Board have been accepted without demure. Once again we take pleasure in acknowledging the aid rendered by the Associate Editors in Crops and Soils and their corps of Consulting Editors. To these men alone belong the credit for maintaining the scientific standards of the JOURNAL which we cherish so highly.

The 1943 volume of the JOURNAL will complete 35 years of official publication by this Society. Your organization and your publications have withstood the impact of two world conflicts. In the midst of the greater one of these you hold a highly stragetic position on one of the most important of all the many "fronts" of this complex struggle—the mighty battle for food and more food for our armed forces, for our allies, for ourselves, and for the job of rehabilitation that will remain after the guns stop firing. Many of the answers to problems arising on the food production front are to be found in your JOURNAL, and upon many of you fall the responsibility of interpreting and putting into action the agronomic findings that help provide the food that is so sorely needed in such great abundance.

Much that we do may lack the glamor of gold braid and active military duty, but the times challenge our best efforts and the opportunities and responsibilities that are ours in helping meet a national crisis offer rich rewards in the satisfaction of having a vital place in the war effort. It is our earnest desire that the JOURNAL measure up in every respect to your expectations and to the needs of the times.

Respectfully submitted,

J. D. LUCKETT, *Editor.*

## REPORT OF THE SECRETARY

THE membership changes in the Society during the past year are as follows:

| | | |
|---|---|---|
| Members, October 31, 1942 | | 1,153 |
| New members | 148 | |
| Reinstated members | 7 | |
| Dropped | 83 | |
| Resigned | 11 | |
| Deceased | 5 | |
| Net increase | | 56 |
| Membership, October 29, 1943 | | 1,209 |

The changes in subscriptions are as follows:

| | | |
|---|---|---|
| Subscriptions, October 31, 1942 | | 493 |
| New subscriptions | 61 | |
| Subscriptions reinstated | 7 | |
| Subscriptions dropped | 42 | |
| Net increase | | 26 |
| Subscriptions, October 29, 1943 | | 519 |

The paid up membership and subscription list by states and countries is as follows:

| | Members | Subscribers |
|---|---|---|
| Alabama | 22 | 1 |
| Arizona | 16 | 6 |
| Arkansas | 9 | 6 |
| California | 67 | 15 |
| Colorado | 17 | 1 |
| Connecticut | 12 | 4 |
| Delaware | 3 | 2 |
| District of Columbia | 72 | 48 |
| Florida | 27 | 5 |
| Georgia | 17 | 6 |
| Idaho | 7 | 2 |
| Illinois | 59 | 20 |
| Indiana | 34 | 5 |
| Iowa | 37 | 4 |
| Kansas | 40 | 3 |
| Kentucky | 12 | 5 |
| Louisiana | 22 | 8 |
| Maine | 3 | 1 |
| Maryland | 33 | 4 |
| Massachusetts | 9 | 6 |
| Michigan | 28 | 5 |
| Minnesota | 37 | 9 |
| Mississippi | 17 | 4 |
| Missouri | 20 | 6 |
| Montana | 8 | 6 |
| Nebraska | 37 | 3 |
| Nevada | 3 | 1 |
| New Hampshire | 2 | 1 |
| New Jersey | 20 | 6 |
| New Mexico | 10 | 4 |
| New York | 51 | 29 |
| North Carolina | 31 | 7 |
| North Dakota | 17 | 1 |
| Ohio | 41 | 9 |
| Oklahoma | 12 | 6 |
| Oregon | 17 | 4 |
| Pennsylvania | 27 | 9 |
| Rhode Island | 6 | 0 |
| South Carolina | 20 | 2 |
| South Dakota | 10 | 1 |
| Tennessee | 19 | 5 |
| Texas | 51 | 20 |
| Utah | 23 | 7 |
| Vermont | 4 | 1 |
| Virginia | 18 | 3 |
| Washington | 19 | 5 |
| West Virginia | 9 | 1 |
| Wisconsin | 43 | 7 |
| Wyoming | 7 | 1 |
| Alaska | 1 | 1 |
| Hawaii | 4 | 8 |
| Puerto Rico | 2 | 4 |
| Africa | 4 | 32 |
| Argentina | 11 | 17 |
| Australia | 0 | 27 |
| Bolivia | 0 | 1 |
| Brazil | 2 | 8 |
| British Guiana | 0 | 1 |
| British West Indies | 1 | 2 |
| Canada | 24 | 28 |
| Ceylon | 0 | 2 |
| Chile | 4 | 1 |
| Colombia | 2 | 3 |
| Cuba | 2 | 4 |
| Egypt | 0 | 1 |
| El Salvador | 2 | 0 |
| England | 1 | 13 |
| Fiji | 0 | 1 |
| Guatemala | 0 | 2 |
| Haiti | 1 | 0 |
| Honduras | 1 | 1 |
| India | 3 | 13 |
| Ireland | 0 | 1 |
| Mauritius | 0 | 1 |
| Mesopotamia | 0 | 1 |
| Mexico | 3 | 2 |
| New Zealand | 0 | 6 |
| Nova Scotia | 2 | 0 |
| Palestine | 0 | 1 |
| Peru | 3 | 3 |
| Portugal | 0 | 2 |
| Scotland | 3 | 1 |
| Spain | 0 | 2 |
| Uruguay | 1 | 0 |
| U. S. S. R. | 1 | 0 |
| Venezuela | 2 | 2 |
| Wales | 0 | 3 |
| Total | 1,205 | 510 |

The increase in membership is particularly gratifying. At present we have only four members who have not paid for 1943. Our total paid up membership

of 1,205 is the highest in our history. The increase in subscribers is small but does indicate continued interest in the JOURNAL wherever it can be secured.

The efforts of various members of the Society in helping to secure new members and to retain old ones is deeply appreciated. Your continued support will help to build our Society during this critical period.

Respectfully submitted,

G. G. POHLMAN, *Secretary.*

## REPORT OF THE TREASURER

I BEG to submit herewith the report of the Treasurer for the year ending October 31, 1943.

### RECEIPTS

| | |
|---|---|
| American Society of Agronomy | $13,480.30 |
| Soil Science Society of America | 5,358.40 |
| Marbut Memorial fund | 524.71 |
| International Society of Soil Science | 55.00 |
| Endowment fund, International Society of Soil Science | 23.10 |
| Total receipts | 19,441.51 |
| Balance on hand, October 31, 1942 | 3,619.26 |
| Total income | $23,060.77 |

### DISBURSEMENTS

| | |
|---|---|
| American Society of Agronomy | 13,550.60 |
| Soil Science Society of America | 5,966.91 |
| Marbut Memorial fund | 1,281.01 |
| International Society of Soil Science | 440.00 |
| Total disbursements | $21,238.52 |
| Balance | 1,822.25 |
| Checks outstanding | 3.10 |
| Balance in bank, October 29, 1943 | 1,825.35 |
| Balance in savings bonds | 2,520.00 |
| Total assets, October 29, 1943 | $ 4,345.25 |

These assets are divided as follows:

| | Cash in bank | Savings bonds | Total |
|---|---|---|---|
| American Society of Agronomy | $ 746.77 | | $ 746.77 |
| Soil Science Society of America (deficit) | −623.11 | | −623.11 |
| Marbut Memorial fund | 306.94 | | 306.94 |
| International Society of Soil Science | 1,152.48 | | 1,152.48 |
| Endowment Fund, I.S.S.S. | 242.27 | $2,520.00 | 2,762.27 |
| Total assets | $1,825.35 | $2,520.00 | $4,345.35 |

A breakdown of receipts and disbursements for the American Society of Agronomy for the year ending October 29, 1943 is as follows:

RECEIPTS

| | |
|---|---|
| Convention receipts | $ 919.60 |
| Miscellaneous receipts | 52.32 |
| Advertising | 1,323.34 |
| Reprints sold | 1,767.83 |
| JOURNALS sold | 320.02 |
| Subscriptions, 1942 | 368.15 |
| Subscriptions, 1943 (old) | 2,174.85 |
| Subscriptions, 1943 (new) | 292.40 |
| Subscriptions, 1944 (advanced) | 310.20 |
| Dues, 1942 | 111.15 |
| Dues, 1943 (old) | 4.968.01 |
| Dues, 1943 (new) | 725.05 |
| Dues, 1944 (advanced) | 114.18 |
| Index | 6.00 |
| Abstracts | .60 |
| Total receipts | $13,453.70 |
| Transfer from International Society of Soil Science | 26.60 |
| | $13,480.30 |
| Balance in cash, October 31, 1942 | 813.97 |
| Total income | $14,294.27 |

DISBURSEMENTS

| | | |
|---|---|---|
| Printing the JOURNAL, cuts, etc | | $ 9,675.70 |
| Salary of Editor | | 733.40 |
| Postage, Editor and Secretary | | 211.51 |
| Miscellaneous printing | | 194.20 |
| Mailing clerk and stenographer | | 1,273.45 |
| Refunds, checks returned, etc | | 18.05 |
| Miscellaneous | | 231.39 |
| Expenses for meetings | | 1,212.90 |
| Total disbursements | | $13,550.60 |
| Total income | $14,294.27 | |
| Less total disbursements | 13,550.60 | |
| Balance on hand, Oct. 29, 1943 | 743.67 | |
| Checks outstanding | 3.10 | |
| Balance in bank, October 29, 1943 | | $746.77 |

The receipts are higher than last year, but expenditures were also higher, with the net result that we have $70.30 less in the treasury of the American Society of Agronomy than last year. Although this is not a large sum, it would seem wise to scrutinize carefully our expenditures and to look for means of increasing our income so that we can continue to show a favorable balance.

Respectfully submitted,

G. G. POHLMAN, *Tresaurer.*

## AUDITING COMMITTEE

THE members of the Auditing Committee have examined the books of the Treasurer of the American Society of Agronomy and find the accounts correct as reported.

A. T. WIANCKO
G. W. CONREY, *Chairman*

## FERTILIZERS

### FERTILIZER GRADES

MEMBERS of the subcommittee in association with other agronomists and federal agencies have given much attention to the selection of a limited number of fertilizer grades to be sold in each state and particularly to the attainment of greater agreement between grades recommended in adjoining states. Consideration has also been given to procedures by which the number of grades to be sold in a given state after the war may be limited through mutual agreement between the industry, control officials, and agronomists. Agronomists in each state have been encouraged by members of the committee to collect from fertilizer companies the tonnages of different grades sold in the states each season. These data are entirely confidential and are compiled into a summary which is distributed to all companies submitting sales reports. This collection of sales data by agronomists has grown to be a regular procedure in a considerable number of states and constitutes a helpful contact between industry and agronomists.

C. E. MILLAR, *Chairman*

### DIAGNOSIS OF NUTRIENT STATUS OF SOILS AND PLANTS

GOOD progress was made in stimulating interest among plant scientists in the diagnostic procedure. A number of papers were published during the year on various phases of this subject.

The effort of this committee in building a file or reference library of case histories is meeting with some success. A number of such cases will be published annually in the JOURNAL. It is suggested that those especially interested secure reprints from the authors. In all instances the authors of the case histories are to keep a supply of mimeographic copies available for distribution upon request. It is the hope of the committee that this file will serve as a handy reference on the subject.

The case histories collected to date have come entirely from members of the committee. This is not enough, therefore all scientists are invited to write up briefly, one page if possible, their experiences in diagnosing the nutrient status of soils and plants and send them to the Chairman, who will assemble all the cases for annual publication following the annual meeting of the Society.

GEORGE D. SCARSETH, *Chairman*

### NITROGEN UTILIZATION

THE members of the Subcommittee on Nitrogen Utilization operated entirely by correspondence. Since every member of the Subcommittee was also a member of the National Joint Committee on Nitrogen Utilization, it was thought that we should function largely through the subcommittee of the National Joint Committee. During the course of the year, however, the Subcommittee did consider and act on one specific matter on which we wish to report.

Under date of June 2, the Subcommittee received from J. H. Stallings, Production Programs Branch, Food Production Administration, U. S. Dept. of Agriculture, Washington, D. C., three large sheets of data that had been compiled from publications of the several state agricultural experiment stations. These data showed:

1. Returns from pasture fertilization in terms of the composition of dry matter.
2. Returns from pasture fertilization in terms of digestible nutrients and of equivalent production of milk, beef, corn, wheat, oats, and cottonseed meal.
3. Returns from fertilization of hay crops in terms as shown in item 2.

These data were studied by the members of the Subcommittee with the result that on August 18 a letter was sent to Dr. Stallings asking him to extend his studies in an effort to translate the effects of fertilizers on haylands and past res into the following terms:

a. Pounds dry matter, protein, milk, and meat per pound N, $P_2O_5$, and $K_2O$.
b. Mineral content of plant produce as influenced by applications of N, $P_2O_5$, and $K_2O$.

A preliminary report on this was made by Dr. Stallings in early October. From this tentative report it was apparent that considerable further study would have to be undertaken to get a complete picture of our present knowledge on these matters, but progress is being made and, in due time, it should be possible to present some fairly dependable figures on the returns per pound of applied N in terms of the units mentioned.

It may be well to add, however, that experiments seldom give the best picture that could be presented for any given fertilizer element. Some limiting factor usually operates to prevent full effects from the element under study. We should be able to get larger and larger returns per pound of N in proportion as we know when, and when not, to use it. In other words, there are conditions under which its use can only result in negative effects. The problem is to eliminate such cases and study the use of N where the element has a real chance to do its work.

F. E. BEAR, *Chairman*

### FERTILIZER APPLICATION

THE Subcommittee on Fertilizer Application has continued to participate in the work of the National Joint Committee on Fertilizer Application. This has involved experiments in approximately 20 states on both field and vegetable crops. Comparisons have been made between the usual row or broadcast surface applications, and applications made by applying the fertilizer on the surface and plowing under, and by applying in bands at the bottom of the furrow; also various combinations of surface and plowing under. War conditions have necessitated some curtailment of the research program, but there has been an increase in the number of demonstrations relating to fertilizer application.

The work of this Subcommittee and the National Joint Committee on Fertilizer Application has undoubtedly materially contributed to the more effective use of fertilizers during the war period.

ROBERT M. SALTER, *Chairman*

## SOIL TILTH

THIS report is the product of this and all previous committees' activities. It discusses soil tilth, considers the need for tilth research, presents a broad research program, and states specific objectives for 1944.

### DISCUSSION OF SOIL TILTH

It is difficult and perhaps impossible to define tilth in terms that will meet with general approval. This results from the broad usage of the term by farmers, teachers, engineers, and soil and plant scientists. A particular individual using the term tilth is influenced by certain interests and defines tilth in terms of his interests. Depending upon interests tilth signifies to different individuals the act of tilling, the tilled layer, the zone of roots, the physical condition of the soil

as it affects tillage, the physical condition of the soil as it affects plant growth, the feel of the soil, the physical condition of the soil, ease of handling, etc. Little can be gained by some particular group defining tilth in terms of their interests with the hope that others will use the term in the same sense. One way of avoiding difficulties is for each individual using the term in a publication to define tilth in the sense he intends to use it so that readers will not be mislead. Another possibility is to coin a new term that can be restricted to a particular usage of the now-too-general term, tilth.

This report concerns the physical condition of soil in its relation to life within the soil. Your committee has chosen the term "biophysical condition of soil" for this restricted meaning of tilth. Biophysical condition is not synonymous with physical condition. The physical condition of soil refers to a specific state of existence, and can be described entirely in physical terms. A given physical condition may represent many biophysical conditions depending upon the soil, organism and climate involved. While biophysical condition has a more restricted meaning than tilth it is still far too general to permit us to deal with the separate entities in the entire system or with their interrelations. For this reason we have selected the term "specific biophysical condition of soil" which denotes the physical condition of a given soil in its relation to a particular organism in a particular climate. The specific biophysical condition of soil may then be evaluated in terms of plant response. When we have learned how to characterize the physical condition of soil adequately we will probably be able to evaluate the specific biophysical condition in terms of soil qualities.

The soil characteristics that influence the biophysical condition are those that affect the air, water and temperature relations and possibly also the resistance to penetration. On a given soil, temperature relations and the resistance to penetration are largely governed by the air and water regime. It follows probably that an adequate description of the air and water interrelations in a soil would characterize the physical state of that soil as it affects plants.

The description of the air-water regime involves a knowledge of the amounts and distribution of both air and water in the soil. It also involves a knowledge of rates of movement. Thus a puddled surface soil or a compacted horizon assumes great importance.

It must be recognized that the biophysical condition is continually changing. Even in a soil in which the physical state does not change with time, the biophysical condition changes with changes in the amounts of air and water present. Where the physical state changes with time as is usually the case, the biophysical condition fluctuates markedly. The physical state is altered greatly by tillage, by the action of rain, by growing roots, and other biological activities, by wetting and drying, by freezing and thawing, and by chemical weathering.

In the remainder of this report tilth is used synonymously with biophysical condition.

## THE NEED FOR TILTH RESEARCH

Approximately two-thirds of the total power consumption in farm draft work in the United States is expended in tillage. Over half this power is used in the basic operations of plowing and listing. One of the major objectives of tillage is to improve soil tilth. Cases can be cited where much of the money invested in tillage is wasted. Under other conditions, changes produced by soil manipulation effect such surprising increases in crop production as to suggest that an extension of the knowledge relative to the effects of tillage on soil and

subsequent crop growth might lead to a more economic system of soil management.

Tillage experiments in the past have compared implements or number of operations in their effects on yield. In none of these experiments has soil tilth been evaluated either before or after tillage. It is not surprising that results obtained by one investigator do not agree with those obtained by others. Nor is it surprising that a treatise such as "Plowman's Folly" has received so much publicity. The reason soil tilth has not been evaluated in tillage experiments is that methods are not available by which it can be determined. Neither do we know with any degree of certainty what soil tilth is required for our important crop plants.

No amount of empirical experimentation will tell us whether sub-surface tillage is superior to plowing, whether plowing is superior to disking, or what changes are desirable in the design of tillage machinery. Before we can make real progress we must know what soil physical state is desired for a given crop under specified climatic conditions. We must be able to measure the changes produced in soil tilth by our different management practices. A thorough fundamental study of soil tilth would seem to be of basic importance to agriculture.

## A PROGRAM OF TILTH RESEARCH

Your committee believes research must answer quantitatively the following questions:

1. What are the soil tilth requirements of our important crops?
   (a) Air requirements
   (b) Water requirements
   (c) Temperature requirements
   (d) Resistance to root penetration
2. What is the soil tilth of a given soil before tillage?
3. How can soil in a given physical state be placed in state having desired tilth?
   (a) Engineering aspects
   (b) Soil aspects
   (c) Cropping and microbiological aspects
   (d) Environmental aspects
4. How stable is the soil tilth created by tillage?
   (a) Effect of soil type
   (b) Effect of previous cropping
   (c) Effect of tillage
   (d) Effect of climate and weather
5. Can guides be set up in terms of soil, crop and environment to serve as a basis for engineering processes to establish desired tilth?

## ORGANIZATION OF TILTH RESEARCH

Soil tilth and tillage present problems of national importance. Only by joint action of federal and state agencies can we hope to obtain solutions to these problems.

In the above incomplete analysis of the tilth problem, it is evident that certain phases of the research must be carried out under closely controlled labora-

tory conditions (in deciding the tilth requirements of crops it will be necessary to control light, temperature, moisture, soil air, atmosphere, nutrients, and soil structure) while other phases of the research will require field plots under widely varying conditions. The Joint Committee has already recommended that a national laboratory be established to study soil tilth and it reiterates that recommendation now. The committee believes the tilth requirements of crops can best be ascertained at the national laboratory. All phases of the research would be cooperative between the national laboratory and the state stations. It would seem desirable to divide the country into regions where problems were similar. A group of collaborators from each region would then work with the national laboratory in formulating a program of research for that region. Undoubtedly there would be certain phases of the program that could be best investigated by the state experiment stations while other phases would require the controls existing at the national laboratory.

Our conception of the national tilth laboratory is that as it is an integral part of the Department of Agriculture, this program would not require the creation of any new agency or any reorganization within the Department. It would, however, require that funds be provided for the Bureau of Plant Industry, Soils, and Agricultural Engineering, to establish and operate additional facilities consisting of laboratories, greenhouses, various control apparatus, etc., for studying the plant physiological effects of various tillage practices and conditions of tilth and to supplement and work in connection with the machinery tillage laboratory. The activities of the laboratory would be decided cooperatively by the several states, the Soil Conservation Service, and the Bureau of Plant Industry, Soils, and Agricultural Engineering. We feel that tilth is a pressing problem of national concern and as such merits national attention.

## OBJECTIVES FOR 1944

The committee realizes that very little new work on tilth will be possible until after the war. Also, granting that a program such as the one proposed is adopted, it will be some time before plant requirements can be evaluated. Because of this it would appear desirable to evaluate, insofar as possible, the changes produced in the physical state of soil by our present tillage implements. This knowledge is certain to be the basis of any future activities aimed at creating desired tilth.

Many experiment stations are now comparing plowing with sub-surface tillage. It may be that it would be possible to include disking also. These three methods constitute our present essentially different approaches to seedbed preparation. In one the residues are turned under, in another left on top of the ground, and in the third the residues are mixed in the surface soil.

The committee recommends that as many experiment stations as can do so, compare these three methods of tillage on one or more important crops. In addition to yields, as much information should be obtained as possible that will reflect on the air-water regime in the soils studied. In the event the physical studies cannot be made, it will be enlightening to have yields only.

The committee further recommends that it be authorized to submit this report to each of the directors of the several state experiment stations for their consideration. If a majority believe that a program along the lines suggested in this report is desirable, the report and the statements of the directors shall be submitted to the Administrator of Research of the Department of Agriculture

with the request that he approve the program and take such steps as are necessary to put the program into effect, as soon as conditions permit.

B. T. SHAW, *General Chairman*

| For the American Society of Agronomy | For the American Society of Agricultural Engineers |
|---|---|
| L. D. BAVER | M. L. NICHOLS |
| E. N. FERGUS | J. H. NEAL |
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| | I. F. REED, *Chairman* |

## WAR AND POST-WAR ADJUSTMENTS

ONCE again the American Society of Agronomy meets with our nation still occupied with the conduct of a global war. We are now able to perceive shaping the military victory which is our immediate concern, but with the cessation of hostilities the United Nations will face an *even more prodigious* task in winning the peace. Unless we can win the peace we shall not have achieved true victory and we shall have an interlude which is but an armistice preceding an even greater holacaust. In building the "Temple of Peace", it is obvious to all thinking people that an attempt to provide adequate food for the peoples of the whole world will be a most enduring foundation stone. So huge a task cannot be the responsibility of any one country, but of all countries working in cooperation.

In the early summer of 1943 we were able, for the first time in the history of the world, to witness the co-operative planning of the strategy of peace, for at Hot Springs, Virginia, the government of the Unites States was host to the United Nations Conference on Food and Agriculture. The prime purpose of this conference, which brought together representatives of 44 nations, was to consider the world problem of food production and distribution after the war. The report of the conference shows that the delegates devoted most of their discussions to the problem of providing more and better food for 2,000 million people. The majority of the proposals for expansion of agricultural production, the improvement of nutrition and the increase of consumption are specifically directed to this end. It is a tragic fact that three-quarters of the 1,150 million inhabitants of Asia are living below decent and minimum health standards, that malnutrition exists among large segments of the peoples of Europe, Africa, various colonial territories, South and Central America, and to a lesser extent, in our own land.

It has been estimated that to "ensure all sections of the population. . . have enough of the right kinds of food. . . on a world basis would require expansion of production of the following orders of magnitude: cereals, 50%; meat, 90%; milk and other dairy products, 125%; vegetable oils, 125%; and fruits and vegetables, 300%."

Food policy and agricultural policy are inseparably intertwined, and raising the standard of nutrition among the nations must have profound effects on the domestic policy of every agricultural country. It seems apparent, that to provide these higher standards even only for our own people, would entail a greatly increased output of food. While such considerations are largely the responsibility of government, agronomists must inevitably serve a most significant function in carrying governmental policy into effect.

Conscious of our past successes, yet we must be vitally aware of our future responsibilities in helping to solve the tremendous problems and in making the large adjustments that will be necessary. Last year at this time, a committee of the American Society of Agronomy clearly enunciated certain recommendations which are as urgent now, as then (this JOURNAL, Volume 34, pages 1150–1152). At this juncture, the present committee established to consider War and Post-War adjustments reiterates those and emphasizes their urgency. At the same time it commends to the Society as a whole, as well as to its individual members, the following considerations:

1. Those nations which emerge from the present conflict with their programs of basic research most nearly intact will have the best opportunity of winning the peace. It behooves agronomists, as public servants, to maintain and strengthen standards of professional attainment and practice.
2. We must be able to discern and understand the needs of the times with clarity of vision and purpose so that, in proper perspective, we can correlate our energies and programs of endeavor into an integrated panorama of research, teaching and extension.
3. As agronomists, we shall achieve the greatest good in the shortest time, if we will expand our co-operative efforts, between workers within and between institutions, as well as between our colleagues in other nations. It is probable that there will be many calls from other countries for United States' agronomists to assist these in establishing their own agriculture on a firmer foundation. The loan of well trained agronomists to foreign governments would be one of the most effective aids we could render.
4. Despite the remarkable accomplishments of the past, there are undoubtedly directions in which further improvements can be accomplished in eliminating the less profitable endeavors in agronomic research, extension, and teaching, and in directing greater emphasis to problems of the most vital import to agriculture.
5. We must continue to strengthen and develop programs of plant breeding so that farmers will be able to grow crops that can better withstand the ravages and hazards of diseases, of insects and of weather. Similarly in the field of plant nutrition we must evolve more effective methods.
6. While agronomic extension is accomplishing results of first rate significance, it is essential that we achieve a still higher degree of effectiveness.
7. With the cessation of conflict and the consequent demobilization of the armed services, we must take up with renewed vigor and enterprise the teaching and training programs that have of necessity been temporarily reduced or entirely eliminated. Experience following World War I suggests that teaching institutions will again have a greater influx of students than at any previous time in their history. Departments of Agronomy will most assuredly face tremendous problems concerning adequate teaching personnel, laboratory and class room facilities and quality of instruction. It appears that our government will correctly emphasize education opportunity for our returning servicemen. They will return to our institutions with a large and varied experience of the world in general, and they shall have the right to expect that we as teachers will make our instruction of the most challenging order. They will not be satisfied with pedantic, dull and uninspired instruction, nor will they be in a mood to accept it. A substantial increase in teaching personnel will most certainly be required.

Furthermore, it has been estimated that there may be approximately 1,000,000 servicemen who may be partially disabled, and for whom it will be necessary to devise special courses of instruction and training in order to enable them to be engaged in a productive capacity. It is possible that one-half of these will require courses of college level.

8. The future demands of agronomic research, teaching, and extension will require that we recruit as soon as possible the most promising candidates for instruction and training in these respective fields so that in the greatest degree we can recoup the lost ground occasioned by the war. We must assure these men a sound basic professional training, as well as a good general education that will enable them to undertake their tasks with vision and in true perspective.
9. It is to be expected that after this war, we shall be called upon to help in training the young men of other nations, especially those of Central and South America and China. They will probably come to us in considerable numbers and with varying degrees of accomplishment. As agronomists we shall share in this responsibility and service, and we must be prepared to devote the necessary energy and tact in preparing them adequately for the service of their own peoples.
10. It is urged that agronomic institutions give immediate and urgent consideration to the problem of assuring and safeguarding adequate supplies of foundation seed for the best varieties of important farm crops. As agronomists we carry heavy responsibilities in this respect. This is especially true of adapted corn hybrids, disease resistant varieties of cereals, and superior strains of legumes and grasses. In the past season our own country has faced severe seed shortages of many important crops. An abundant seed supply is as necessary as a sufficiency of munitions. We need it now, both for our own requirements and for all the United Nations, who now of dire necessity must largely depend on the North American continent for meeting present and future seed needs in restoring to productivity the lands ravaged by war.
11. It is recommended that the American Society of Agronomy use the utmost influence in urging the appropriate federal authorities to make more liberal assignments for the manufacture of critically important farm machinery. With the extreme shortage of farm labor now existing and with the very rapid deterioration of existing machinery, this need is vital to the immediate war and post-war periods in maintaining present levels of production for the expanded production that is required.
12. Similarly the Society urges that more adequate consideration be given to the fertilizer requirements of crops vital to the national effort.
13. Since the soil, our greatest material asset, is being depleted even more rapidly than before the war, it is urged that agronomists meet this challenge by stimulating and organizing the general adoption of those practices which both conserve and restore soil productivity.
14. It is recommended that the American Society of Agronomy appoint a committee to survey the possibilities of establishing suitable courses of instruction and training for the servicemen demobilized from the armed forces, and that this committee report to the next annual meeting of the Society.
15. Finally the American Society of Agronomy, as an organization of scientifically trained men, cognizant of their responsibilities toward the nation's

crops program, again pledges itself to give every possible aid and counsel to the government in the national purpose in prosecuting the war and in meeting the challenge of peace.

M. F. MILLER
N. P. NEAL
R. D. LEWIS, *Chairman*

## EXTENSION PARTICIPATION

AT A conference during the American Society of Agronomy meetings at St. Louis in November, 1942, the extension agronomists favored presenting a request for a special session for extension agronomists at the 1943 meeting. This request was granted. Correspondence with chairmen of departments and extension agronomists throughout the country indicated that for the 1943 session at Cincinnati, a majority favored the presentation of extension methods rather than research material. This expression of opinion guided the Committee in formulating the program presented at the 1943 meeting.

At the conclusion of the 1943 session, a motion was adopted requesting the Committee to appoint a Subcommittee to work with Dr. L. F. Graber in the preparation of a paper for publication in the JOURNAL, summarizing the discussion lead by Dr. Graber, dealing with the subject "Should Extension Agronomists be Employed in Part-time Research?" The Subcommittee appointed includes Dr. E. L. Worthen of New York; Dr. C. F. Simmons of Arkansas; and Dr. W. H. Pierre of Iowa.

At the same time it was agreed that the subject, "Integration of Research and Extension" should be presented at a general session of the 1944 meeting of the Society. It was agreed that although there be separate extension sessions at subsequent meetings, subjects such as the following, of interest to both research and extension men, be included in the general research program: (1) Presentation of research material by a research worker, followed by a report of the activation of this material by an extension worker; (2) summarization of research material dealing with subjects of special interest.

O. S. FISHER
IDE P. TROTTER
L. E. WILLOUGHBY
EARL JONES
D. L. GROSS, *Chairman*

## BIBLIOGRAPHY OF FIELD EXPERIMENTS

THE committee has compiled a bibliography of 124 titles of the more important contributions on the methodology of and interpretation of results of field, pasture, and range experiments, either reported since or not included in the revised bibliography published in this JOURNAL (Vol. 25: 811–828, 1933; and the additions in Vol. 27: 1013–1018, 1935; Vol. 28: 1028–1031, 1936; Vol. 29: 1042–1045, 1937; Vol. 30: 1054–1056, 1938; Vol. 31: 1049–1052, 1939; Vol. 32: 984–986, 1940; Vol. 33: 1124–1127, 1941).

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F. R. IMMER
H. M. TYSDAL
H. M. STEECE, *Chairman*

## VARIETAL STANDARDIZATION AND REGISTRATION

THE following crop varieties have been submitted to the committee during the year, and have been approved for registration:

### BARLEY

*Glacier*, developed by the Montana Agricultural Experiment Station and the U. S. Dept. of Agriculture.

### FLAX

*Crystal*, developed by the Minnesota Agricultural Experiment Station and the U. S. Dept. of Agriculture.

*Royal*, developed by Dr. J. B. Harrington at the University of Saskatchewan.

### OATS

*Cedar*, developed by the Iowa and Nebraska Agricultural Experiment Stations and the U. S. Dept. of Agriculture.

### SORGHUM

*Westland*, developed by the Kansas Agricultural Experiment Station.

### SOYBEANS

*Patoka*, developed by the Purdue University Agricultural Experiment Station and the U. S. Dept. of Agriculture.

*Gibson*, developed by the Purdue University Agricultural Experiment Station, and the U. S. Dept. of Agriculture.

*Earlyana*, developed by the Purdue University Agricultural Experiment Station and the U. S. Dept. of Agriculture.

WHEAT

*Fairfield*, developed by the Purdue University Agricultural Experiment Station.

*Carleton*, developed by the North Dakota Agricultural Experiment Station and the U. S. Dept. of Agriculture.

*Stewart*, developed by the North Dakota Agricultural Experiment Station and the U. S. Dept. of Agriculture.

*Newthatch*, developed by the Minnesota Agricultural Experiment Station and the U. S. Dept. of Agriculture.

Descriptions of these new varieties will be published in the JOURNAL.

In accordance with the authorization approved by the Crops Section of the Society at the 1942 annual meeting, the committee is considering final plans for the registration of improved varieties of various grasses.

During the year, the committee also approved a general plan for the registration of improved varieties developed by private plant breeders. Under this plan, the agricultural experiment station of the state in which the private breeder is resident will be requested to assume responsibility for conducting the necessary tests and for officially sponsoring the request for registration. In view of the fact that a number of varieties of various crops developed by private plant breeders have proved outstandingly valuable and are now on the list of recommended varieties in various states, this seems to be a desirable move. The committee believes that the Society should recognize valuable germ plasm and meritorious accomplishment from whatever source it may come.

A. C. ARNY
H. B. BROWN
J. A. CLARK
E. F. GAINES
L. F. GRABER
H. K. HAYES
E. A. HOLLOWELL
R. E. KARPER
W. J. MORSE
T. R. STANTON
T. M. STEVENSON
G. H. STRINGFIELD
M. A. MCCALL, *Chairman*

## NOMENCLATURE OF GENETIC FACTORS IN WHEAT

THE committee has continued work throughout the year. A proposed set of symbols and system of nomenclature has been agreed upon. The symbol consists of the initial letter of the name of the character or of the initial letter of some other appropriate word in the name. Numerical subscripts will designate different gene symbols for a character. This system is flexible and can be expanded easily. Only characters which have been studied sufficiently to determine their inheritance will be given subscripts.

Some of the committee members have been unable to submit detailed reports on the characters assigned to them due to the war. However, it is hoped to receive these reports in the near future so that a complete report can be submitted to the society.

It is recommended that the present committee be continued another year.

FRED N. BRIGGS
L. P. REITZ
W. W. WORZELLA
J. B. HARRINGTON
E. R. AUSEMUS, *Chairman*

## METHODS OF SEED PRODUCTION AND UTILIZATION OF IMPROVED STRAINS OF FORAGE CROPS

AT THE Washington meeting in 1941 the Extension Committee of the Society recommended the appointment of, "A standing committee composed of research and extension men from important seed producing and seed using areas to correlate the production and utilization of improved strains of forage crops". Literally interpreted, this committee might result in conflicts with the work of several other organizations and groups. So this committee regards its prime function is to call the attention of all agronomists to:

1. Developments in superior strains of forage crops having probable regional significance.
2. Significant interstate programs for the production and utilization of improved strains of forage crops.
3. Situations and processes requiring solutions and actions to aid in gaining effective production, utilization, and preservation of improved strains of forage crops having regional significance.

First, we commend the officers of the Crops Section of the Society for the many contributions at this Cincinnati meeting to methods of breeding forage crops and to the problems of seed production and seed processing.

Experience has shown, however, that much good germplasm has remained unutilized as a result of unsolved problems in producing and distributing the seed, or as a result of lack of planning for seed production, or because of inadequate knowledge and appreciation by agronomists as well as by farmers of the values of improved strains or composites having regional (interstate) significance.

We believe it fundamental that, with the advent of more and more improved strains for forage crops, agronomists, seed producers, seedsmen, and farmers must fully appreciate that the production of seed of the affected crops will be shifted from incidental, "side-line", or "commodity" enterprises to deliberate planned programs of production and distribution.

At this time, the committee calls the attention of agronomists to the following relatively new improved strains and composites which have regional significance and whose performance probably justifies greater efforts in seed production and extension of use in those states to which they are specifically adapted:

Cumberland red clover (Reg. No. 1).[1]
Midland red clover (Reg. No. 2).[1]
Evergreen biennial white sweet clover (Reg. No. 3).[2]
Spanish biennial white sweet clover (Reg. No. 1).[2]
Madrid biennial yellow sweet clover (Reg. No. 2).[2]
Ranger, Buffalo, and Atlantic alfalfas
Achenbach, Fisher, and Lincoln strains of brome grass
Marietta, Lorain, and Cornell 1777 timothys
Tift sudan grass

This list is probably not complete and the committee would appreciate information of other strains or composites having regional significance and for which interstate programs of seed production and utilization have been developed.

[1]Hollowell, E. A. Registration of varieties and strains of red clover, I. Jour. Amer. Soc. Agron., 35:830–833. 1943.

[2]Hollowell, E. A. Registration of varieties and strains of sweet clover, I. Jour. Amer. Soc. Agron., 35:825–829. 1943.

With the exception of Atlantic alfalfa and Tift sudan grass, seeds of the above-listed strains and composites were in May-June of 1943 declared eligible for loans at premium rates by the Commodity Credit Corporation.

Interstate programs for the production of seed of improved strains have been developed through the International Crop Improvement Association in cooperation with the states originating the strains, seed producing states, and the Division of Forage Crops of the U. S. Dept. of Agriculture. Midland and Cumberland red clovers, and Ranger alfalfa are gaining rapidly in importance as a result of programs of this type. The Alfalfa Improvement Conference worked closely with the International Crop Improvement Association in developing the seed production program with Ranger.

The significance of seed certification as an aid to stimulating and guiding the increase of seed of improved strains has this year been effectively developed in the general meeting by E. F. Frolik. The International Crop Improvement Association is now in the midst of conducting an extensive analysis of the standards and procedures used in various states in the growing, processing, inspecting, and certifying of improved strains. Greater uniformity of concepts and procedures as between states should logically result, as will also higher standards and a more general realization of the fact that proved superior heredity is the true basis of seed certification.

To the committee have come many instances where plant breeders and seed production agronomists are "floundering around" or seeking information on systems of protecting and increasing superior germplasm of new strains of forage crops, and specifically concerning the policies and methods involved in initiating seed certification systems. As there are many aids to be found in the published proceedings and reports of the International Crop Improvement Association, this committee recommends that forage crop breeders and seed production agronomists acquaint themselves with typical state and interstate programs that have been and are being developed through the International Crop Improvement Association.

| | | |
|---|---|---|
| O. S. Aamodt | L. F. Graber | H. C. Rather |
| H. R. Albrecht | F. V. Grau | H. A. Schoth |
| A. L. Clapp | J. C. Hackleman | H. M. Tysdal |
| O. S. Fisher | E. A. Hollowell | R. G. Wiggans |
| E. F. Frolik | R. D. Mercer | R. D. Lewis, *Chairman* |

## CROP TERMINOLOGY

THIS committee was organized a year ago at the suggestion of the Committee on Terminology of the Soil Science Society of America, which had had several strictly crop terms referred to it for definition.

Uniform usage of technical terms is important, but it cannot be obtained without someone's giving up the use of terms to which he has become accustomed. Before making this necessary, every effort should be made to choose the *best* term, all things considered, including present usage.

The committee does not feel that there is time at the annual meeting to discuss these terms. In order to avoid arbitrary action, the committee is submitting its recommendations on these terms at this meeting and suggesting that they be formally acted upon, after opportunity for amendment, at the next annual meeting. The committee requests that those who have objections to any of these

recommendations write them to any member of the committee. Terms so far submitted to the committee are as follows:

*Ensilage, silage, ensile, and silo*

C. V. Piper wrote in 1924: "Silage was originally called *ensilage*. . . The verb form *to ensile* is now preferred". Since this has been the most general usage for at least 30 years, the Committee recommends that we use *silage* rather than ensilage for the noun, and *ensile, ensiling, ensiled* as the verb forms.

*Grass silage, hay crop silage, meadow crop silage, grass, and legume silage*

All of these terms have been used in this country to designate silage made from these grasses, legumes, or mixtures of them which have heretofore been harvested for hay or pasture. The difficulty, of course, arises from the fact that we have no accepted short general term to designate "grasses, legumes, or mixtures of them". *Grass silage* is almost universally used as a general term in other English-speaking countries. In the opinion of the committee, the other circumlocutions are too long ever to win general acceptance, even among agronomists, to say nothing of the public. Consequently we recommend that *grass silage* be used as the general term, and that *alfalfa silage, clover silage, alfalfa-timothy silage*, and similar definite expressions be used where possible.

*Grass seed, forage grass seed, forage crop seeds*, etc.

This set of terms is merely another example of our lack of an accurate general term to include grasses and legumes taken together or separately. Farm usage will probably continue to refer to all small seeds as grass seed. For more precise distinction the committee recommends the use of the term *forage crop seeds*.

*Sward, turf, sod*

These terms are nearly synonymous. All refer to a more or less dense growth of grasses and other similar crops. *Sward* is nearly obsolete and fills no necessary place in technical literature. Insofar as it has any different meaning from the others it is used somewhat more with reference to the *surface*, only, of a lawn, playing field, or other grass growth. *Turf* definitely refers to the matted stratum of earth filled with grass roots, as well as the surface. *Turf* is used in England as *sod* is in this country, for a thin layer of grass-filled earth used to establish grass on a new surface.

These words all connote grass, and there is no word in English which specifically designates a layer of earth filled with roots other than those of grass. Recently, there has been a definite tendency for agronomists to expand the use of sod to include this meaning: e.g., an alfalfa *sod*, a clover *sod*. The committee recommends that this extension of the use of *sod* be encouraged, reserving *turf* for sods composed largely or entirely of members of the grass family.

*Birdsfoot trefoil*

In accordance with rules adopted by "Standardized Plant Names", the committee recommends that this name be written in the form above—no apostrophe, and a compound word rather than a hyphenated word or two words for "birdsfoot".

*Reed canarygrass*

This name is frequently written Reed's canary grass. This name was not derived from a man's name, but from the resemblance of the grass to reeds, so

*reed* should not be capitalized. The committee follows "Standardized Plant Names" in recommending the compound form *canarygrass.*

*Nurse crop, companion crop*

*Nurse crop* is the older, better known term for small grains in which forage crops are sown. It has been used for so long that many persons thought they really were helpful and protective instead of serious and often destructive competitors. Agronomists at the Ohio Agricultural Experiment Station working on seeding problems, looked for a term which more accurately expressed the real relationship between the crops, and in Bulletin 588 of that Station and some earlier mimeographed publications introduced the term *companion crops.* This term is open to several objections, but no better one has been suggested, and the term has been used by many others since the publication of Bulletin 588. The committee recommends that *companion crops* rather than "nurse crops" be used to designate those crops in which other crops are sown. The term may be used to refer to corn, soybeans, and other crops which have never been called "nurse crops".

*Meadow*

In modern agronomic usage, *meadow* always refers to a field in which biennial or perennial crops are grown for hay, and the Committee recommends such use of the word. Historically, the word has been used for any grassland, with the connotation of low-lying land.

K. S. Quisenberry
C. P. Wilcie
C. J. Willard, *Chairman*

(N. B. At the request of Dr. C. J. Willard this report was approved provisionally so as to be subject to amendment, revision and formal action at the next meeting of the Society.)

## STUDENT SECTIONS

IN NEARLY every instance, the Student Agronomy Clubs are inactive, and will no doubt remain so until after the war. Since the last meeting, approximately 400 membership certificates have been issued, which indicates the interest students had in these groups. With the continued support of the Society, the Clubs may be expected to again become active following the war.

As was announced previously, no student essay contest was held this year.

R. L. Cushing
G. H. Dungan
J. B. Peterson
M. B. Sturgis
H. K. Wilson, *Chairman*

## MONOGRAPHS

ALTHOUGH discussions of methods of financing monographs and of suitable subjects are continuing, no definite plans have been developed. The Committee invites suggestions from the members of the Society as to appropriate subjects and prospective authors.

Charles E. Kellogg, *Chairman*

## RESOLUTIONS

YOUR Committee on Resolutions most respectfully calls to the attention of all members of the American Society of Agronomy, the names of seven of our number who have been taken from us since we last met, as follows:

H. L. Westover, Bureau of Plant Industry, U. S. Dept. of Agriculture, Washington, D. C., died January 2, 1943.

W. A. Leukel, University of Florida, Gainesville, Fla., died April 27, 1943.

W. B. Ellett, Agricultural Experiment Station, Virginia Polytechnic Institute, Blacksburg, Va., died May 12, 1943.

G. R. Hyslop, Head of Department of Farm Crops, Oregon State College, Corvallis, Ore., died July 24, 1943.

Alfred Smith, Associate Professor of Soil Technology, University of California, Davis, Calif., died August 24, 1943.

G. M. McClure, Assistant Professor of Agronomy, Ohio State University, Columbus, Ohio, died September 24, 1943.

Fred H. Bateman, A. B. Farquhar Company, Ltd., Greenloch, N. J., died October 13, 1943.

Appended to this report are statements summarizing the life and professional work of our departed members which include the sincere expression of sorrow and loss on the part of the American Society of Agronomy. Our sympathy goes out to their respective families, the institutions they served, and their former associates. Copies of these resolutions as published in the JOURNAL will be sent to the bereaved families.

### TO OUR MEMBERS IN SERVICE

The American Society of Agronomy at its annual meeting in Cincinnati, Ohio, November 10–12, 1943, has keenly missed the presence and the contributions of many of its faithful members who are now in the Armed Services.

To all of these wherever they may be, we send our sincere and cordial greetings. We congratulate each of you on your great and unselfish contribution to our nation's welfare and perpetuation.

May you soon return to us with a wealth of new experiences and observations which will be of value to you and to us in the productive years which lie ahead.

R. I. THROCKMORTON J. D. LUCKETT, *Ex-officio*
R. W. CUMMINGS IDE P. TROTTER, *Chairman*
B. B. BAYLES

### HARVEY LEROY WESTOVER

THE American Society of Agronomy records with deep regret the sudden passing of Harvey Leroy Westover. He died in Washington, D. C., on January 2, 1943, at the age of 63 years.

Today, we pause to commemorate a genial scientist, a tireless worker, a staunch friend, and a benefactor of mankind. We knew him, loved him, and revered him not only for his productive contributions to the advancement of plant science but as a sincere, and generous friend. Soft spoken and modest, yet silently zealous in his work, his extraordinary genius for unassuming leadership and lasting friendships, influenced the wellbeing of mankind here and abroad. His was a mountain of strength born of the grandeur of simplicity and an abiding faith in his work for humankind.

Because of modesty, Harvey Westover would be overwhelmingly embarrassed by the reverent tribute we pay him today. He was America's first and great creative leader in the development of the alfalfa enterprise of our country. No physical or material sacrifice was too great for him to undertake if it promised to solve the intricate problems of the expanding development of rich green alfalfa fields in regions of our nation where its potentialities escaped recognition. Plant explorations by him in Russia, Persia, Turkestan, Africa, Spain, Morocco, Argentine, Chile, and the remote regions of other countries brought to America germ plasm and varieties of alfalfa, superior in cold hardiness and disease resistance—those basic qualities for an enduring culture of America's most beneficient forage.

From the time of its organization in 1933, Harvey Westover served as Permanent Secretary of the Alfalfa Improvement Conference. In this coordination and stimulation of the efforts of American agronomists for the synthesis of superior germ plasm, he kindled and guided a renewed and productive effort. On the very day that he left his desk for the last time, he had recorded the release of the new wilt-resistant Ranger alfalfa.

Harvey Westover was born in Austerlitz, N. Y., on June 4, 1887, the son of Seymour and Anna Gott Westover. After his college work at Cornell where he received his B.S. degree in 1906, he spent five years with the Office of Soil Survey of the U. S. Dept. of Agriculture, and devoted two additional years to the classification of soils for the Forestry Division. In 1913 he joined the Forage Crops Division and began his long, persistent, and notable studies on alfalfa. In 1915 he began his long membership in the American Society of Agronomy.

Westover published many scientific papers not only in the field of his major interest but on other studies such as those of crested wheat grass, fine turfs, and lawns. He was a Fellow of the American Society of Agronomy and of the American Association for the Advancement of Science. He belonged to the Botanical Society of Washington, the American Museum of Natural History, and the Explorers' Club of New York and the Cosmos Club of Washington.

We pay tribute to Harvey Westover not only for his tangible contributions but for intangible ones, perhaps of even greater significance. He has set for us the example of the great power of simplicity, and the far-reaching beneficence of tried and true friendship.—L. F. GRABER.

## WALTER HERMAN ANTHONY LEUKEL

DOCTOR WALTER HERMAN ANTHONY LEUKEL, Agronomist with the Florida Agricultural Experiment Station for the past 17 years, died suddenly April 27, 1943, at his home in Gainesville.

Doctor Leukel was born in Potter, Wis., February 17, 1886. He was educated in the public schools and the State University of Wisconsin, graduating with the B.S. degree in 1916 and received the Ph.D. degree in 1925. He served as instructor and principal of high schools in Wisconsin from 1910 to 1914. He taught in the public schools of California from 1916 to 1918 and in the public schools of Illinois from 1919 to 1922. He was in the Armed Forces of the United States during 1918–19. He joined the staff of the Florida Agricultural Station August 15, 1925.

Through his outstanding research work with the Experiment Station and through his attendance at scientific meetings, Doctor Leukel was widely known throughout the state and respected in Florida farming circles as well as the

scientific world. He attracted widespread attention in the United States and other countries several years ago by developing a special technic for observing root growth of grasses. He was the author of numerous bulletins and scientific articles.

Doctor Leukel was a member of the Catholic Church, American Legion, Phi Sigma, Sigma Xi, American Society of Plant Physiologists, and the American Association for the Advancement of Science. He had been a member of the American Society of Agronomy since 1925. For a number of years he was a member of the Committee of the Boy Scouts of America in Gainesville. He is survived by his widow and two sons of Gainesville; two brothers, John Leukel of Marshfield, Wisconsin, and Bob Leukel of Arlington, Va.; and two sisters, Mrs. Lillian Jones of Oakland, Calif., and Mrs. Charles Pritzil of Brillim, Wis.

Doctor Leukel will be remembered by his associates for his outstanding capacity for careful experimental work, devotion to ideals, and loyalty of purpose. In his death, his family, friends, and science have suffered a great loss.—F. B. SMITH.

## WALTER BEAL ELLETT

WALTER BEAL ELLETT, Head of the Department of Agricultural Chemistry at the Virginia Polytechnic Institute and chemist for the Virginia Agricultural Experiment Station, died in Blacksburg, Va., May 12, 1943.

Doctor Ellett was born at Central Depot, now Radford, Va., November 11, 1874. He was graduated from Virginia Polytechnic Institute in 1894 and was immediately made an instructor in inorganic chemistry, earning his Master's degree in 1896. He went to Germany in 1900 and was graduated from the University in Goettingen in 1904, receiving the M.A. and Ph.D. degrees. While in Germany he studied under Tollens, Wallach, Nernst, Tammann, von Seelhorst, and Fleischmann. He was made chemist of the Virginia Agricultural Experiment Station in 1906. He was also made Head of the Agricultural Chemistry Department at the Virginia Polytechnic Institute in 1915, succeeding the late Professor Robert J. Davidson.

Doctor Ellett was a member of the American Chemical Society, fellow of the American Association for the Advancement of Science, Phi Kappa Phi and Phi Lambda Upsilon honorary fraternities, and had been a member of the American Society of Agronomy since 1910. His researches at the Virginia Polytechnic Institute have resulted in practical contributions to the fields of soil fertility, fixation of phosphoric acid by the soil, fermentation of fruit juices, and pasture research. His many papers have been published in the leading scientific journals and as bulletins of the Virginia Agricultural Experiment Station. In 1926, Doctor Ellett married Miss Anna Burton of Rockbridge County, Virginia, who survives. Doctor Ellett was an inspiring teacher and investigator, and above all, a thorough Christian gentleman.—H. H. HILL.

## GEORGE ROBERT HYSLOP

THE American Society of Agronomy records with deep regrets the sudden passing of one of the outstanding agronomists of the West, Professor George Robert Hyslop.

Professor George R. Hyslop was born in Deshler, Ohio, November 17, 1884; academic education, Ohio State University, graduated, 1907; entered agronomic fields of education, experiment station and extension in Oregon in 1908, and at

the time of his death, July 24, 1943, was head of the Farm Crops Department and Division of Plant Industries at Oregon State College.

This simple chronicle of facts gives little indication of the kind of man he really was. It does not explain why metropolitan dailies wrote editorials mourning his loss, why innumerable farm organizations throughout the state devoted meetings to reminiscences about him, and why thousands of college graduates and students, many of them now in the Army, felt a sudden sense of desolation and personal disaster when they heard the news.

"Prof", as he was affectionately called by thousands, would have been the first to laugh heartily at any suggestion that he was a "great" man. Greatness in his mind was too tied up with ceremony and splendor. It is nearly always the simple things that determine greatness, and these things were possessed by him in a measure far beyond the reach of most of us.

He was simply and unaffectedly interested in people—people of every rank and station. The truck driver with an idea, a barefooted youngster with a whimsical viewpoint, a clerk with an interesting slant on life—all were of equal importance to him and all were of more importance than a person of note but of little personality or responsibility. He had wonderful sympathy, and people of all degrees came to him with their problems with a feeling he would understand and could help them. This quality was invaluable with students, who for more than 35 years streamed through his office, each taking away with him a warm memory of a human, understandable, humorous, and likeable "Prof". People liked him because he liked them with genuineness that no one could feign. He was tolerant of the faults of the rest of us, continually found excuses for lapses in others. Even a genuine rogue could trust in his friendship—provided he were a likeable rogue and not mean.

If one were to fish out a dominant trait, it would have to be generosity—a complete lack of selfishness. When a measure came to attention, his first thought was always, "Is this a good thing for the farmers of the state and the nation?" If the answer were "No", he was no longer interested no matter what might be the effect upon himself. He was thus often drawn into controversies that temporarily turned important people against him. His instant championship of a right measure or a friend who he thought to be in the right had no relationship to what was expedient. He had that rare trait—the ability to divorce his own welfare entirely from the issue. This was a part of his simplicity. There was no involved or tortuous argument, only the question, "Is it right?"

Nearly every professional agricultural worker in Oregon and the Pacific Northwest in general is indebted to him in some degree. He promoted and saw in actuality in conjunction with fellow workers the perfecting of grain certification and grading on a national basis, field and garden seed production development in Oregon from the class of a few hundred thousand dollar business a year to one of several million a year, championed wuth success bulb and fiber flax growing in Oregon, and was a firm advocate and believer that by the use of the right kinds of forage plants and proper management practices the dry land ranges and logged off lands could be developed to the increased benefits of livestock production.

He was on the continual lookout for new or different plants and agricultural practices and the "whys" and "wherefores" in relation to any phase of agriculture.

He was very much interested in agricultural organizations that had to do with the betterment of agriculture and was affiliated with those of importance in Oregon. His rather continuous series of press articles and other publications were

of current importance to the public and the agricultural public in particular and were generally accepted as fact and of definite value.

He would stop in the middle of a field and say, "Why is this part of the field better?" The search might lead back through several previous owners. He tried the patience of fellow teachers by his insistence upon stopping, no matter how inopportune the time, to investigate some flower in a far away field or some peculiar appearance of the grass by the roadside. But this curiosity proved to be the foundation upon which many agricultural discoveries were based, and it continually challenged the work of others and himself—seeking out the errors and demanding proof.

We pay tribute to George Robert Hyslop for his very significant tangible and intangible contributions to mankind and agriculture. To those of us who knew him, the greatest loss lies in the personality of "Prof" himself. We have lost a strong, unflinching friend upon whom to lean, and we can no longer hear his hearty laugh; or enjoy with him an odd, whimsical use of a word; or chuckle with him over some of the human reactions of the people all about.—H. A. SCHOTH.

## ALFRED SMITH

ALFRED Smith, Associate Professor of Soils at the University Farm, Davis, Calif., died suddenly on August 9, 1943. He is survived by his mother; his wife, Bessie Archibald Smith; and one son, Donald, now in the Army. His son, Robert, died in the Army Air Corps a year ago.

Alfred Smith was born in Hazelton, Pa., in 1888, and received his bachelor's and master's degrees at Wittenberg College, Ohio. He was granted his doctor's degree at the University of Wisconsin in 1925. In 1914 he joined the staff of the Division of Soils (then Soil Technology) of the University of California as Instructor, and was subsequently promoted to Assistant Professor and Associate Professor.

Doctor Smith devoted much of his time and energy to teaching. He taught a general course on soils to the regular degree students and also a very popular course on soils to non-degree students. His research work was quite varied and enabled him to obtain first-hand information on numerous soil problems. These experiences helped him in teaching and advisory work. He assisted in soil survey work and carried out experiments on various phases of soil moisture relationships. Gradually he became more and more interested in the various aspects of soil temperature. He installed elaborate recording equipment and studied the march of soil temperature under various climatic and cropping conditions. His findings have been reported in numerous publications, both in scientific journals and in farm papers. Recently he contributed various sections to Gustafson's book on "Soils and Soil Management".

Soon after Pearl Harbor, when the Davis Campus was taken over by the Army, Doctor Smith again joined the Soil Survey and collaborated in surveying lands suitable for the production of guayule in the San Joaquin Valley.

Doctor Smith was a fellow of the American Society for the Advancement of Science, an honorary member of Alpha Zeta, a member of Sigma Xi, the American Society of Agronomy, the Soil Science Society of America, and the Western Society of Soil Science.—HANS JENNY.

## GEORGE MATTHEW MCCLURE

GEORGE MATTHEW MCCLURE, Assistant Professor of Agronomy, College of Agriculture, the Ohio State University, and Assistant Agronomist, Ohio Agricultural Experiment Station, died in Columbus, Ohio, on September 24, 1943, at the age of 54, after a long illness.

Born at Wooster, Ohio, on December 4, 1888, he attended Wooster College, and later the Ohio State University, receiving the B.A. degree in 1914 and an M.S. in 1916. From 1909 to 1912 he was chemist at the Ohio Agricultural Experiment Station, Wooster. In 1914, he was made Assistant in Agricultural Chemistry at the Ohio State University and a year later was made Instructor in Agricultural Chemistry and Soils. In 1925 he was appointed Assistant Professor of Soils. Since 1927 he has also been Assistant Agronomist, Ohio Agricultural Experiment Station.

On October 16, 1912, Professor McClure was married to Miss Orpha Mae Koontz, who survives, together with a son George, a senior in Engineering at Ohio State University and who will shortly enter the Army Air Corps, and a daughter, Mrs. Wesley Zaugg, wife of a Major in the Army Air Corps.

Professor McClure's special interest was in the field of Soil Chemistry and its application. Graduate and undergraduate students attest to the thoroughness and inspiration of his teaching and counselling. Enthusiastically devoted to the development of grassland areas, he became a national authority on the design and construction of golf courses, parks, and lawns. The Ohio State University golf course stands as a physical memorial to this devotion.

Professor McClure was a member of numerous organizations, including the University Lodge of Masons, of which he was past master, Delta Tau Delta, Alpha Gamma Rho, Phi Lambda Upsilon, the American Chemical Society, and for many years the American Society of Agronomy.—R. D. LEWIS.

## FREDERIC HARLAN BATEMAN

FREDERIC HARLAN BATEMAN, long a member of the American Society of Agronomy and widely known for his highly important contributions to the development of improved potato-planting machinery, died peacefully at his farm home at Grenloch, N. J., October 13, 1943, at the age of 70. He is survived by Lavinia Steele Bateman, his wife, and by Frank, Frederic S., William, Ellen, and Alice (Mrs. Wallace Craig), all children by his first wife, Ellen Brace.

Mr. Bateman was born at Spring Mills (now Grenloch) on May 7, 1873. After attending Peddie Institute and graduating from Eastbourne Academy, he entered the employ of the Bateman Manufacturing Company, founded by his grandfather, Stephen Bateman, in 1836, and later directed by his father, Frank Bateman. Early in his career he took over the active management of the business and soon became president of the reorganized Fred. H. Bateman Company which continued the production of the widely known "Iron Age" line of farm machinery. Subsequently, this company was merged with the A. B. Farquhar Company of York, Pa., with which organization Mr. Bateman continued to serve in the capacity of manager of the "Iron Age" division until his death.

Being also a practical farmer, Mr. Bateman soon saw possibilities for improvement in fertilizer placement with the result that he spent a large part of his life perfecting machinery for planting potatoes, cotton, tobacco, and vegetables. Within recent years he developed a "Hi-Lo" placement by which fertilizer is

banded at the usual level on one side of the row and several inches deeper on the other, with resulting improvement in yields in many cases.

During the course of a very successful business career, Mr. Bateman was honored by the presidency of the Potato Association of America in 1937. In 1938 he was awarded a medal of honor by the Pennsylvania Cooperative Potato Growers Association, and in 1942 the gold medal of the New Jersey Agricultural Society was awarded him by the New Jersey State Potato Association. He was elected a Fellow of the American Association for the Advancement of Science in 1940, and in 1941 was elected General Chairman of the National Joint Committee on Fertilizer Application and presided at the annual meeting in St. Louis in 1942. At this time he was presented with a handsome album of letters from friends prominent in agronomy and the fertilizer industry, expressing appreciation of the high esteem in which he was held as a man and for his valued contributions to fertilizer placement and to agriculture in general. In January 1943 he was given a citation for "outstanding service to Agriculture" by the New Jersey State Board of Agriculture.

The people of his home community thought of him as the genial Superintendent of the Sunday School, in which capacity he served 25 years. For a period of 44 years he served as Elder in the Presbyterian Churches of Blackwood and Grenloch, and was also for many years a member of the Board of Trustees. With the passing of this scientist, manufacturer, farmer, and Christian gentleman, we have lost a highly esteemed associate and friend.—F. E. BEAR.

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## MINUTES OF THE CROPS SECTION OF THE AMERICAN SOCIETY OF AGRONOMY

THE business meeting of the Crops Section of the Society was held on Friday morning, November 12, 1943, in Cincinnati, Ohio.

The reports of the committees on Varietal Standardization and Registration, Nomenclature of Genetic Factors in Wheat, and Methods of Seed Production and Utilization of Improved Strains of Forage Crops were read and approved. The report of the committee on Crop Terminology was presented by Dr. C. J. Willard with the request by him that it be approved provisionally, subject to amendment and formal action at the next meeting. This report was so approved. All these reports appear elsewhere in this JOURNAL as a part of the Minutes of the Thirty-sixth Annual Meeting (pages 1050 to 1055).

The Nominating Committee, consisting of Dr. H. K. Hayes, *Chairman*, Dr. O. S. Aamodt, Dr. B. A. Brown, Dr. D. W. Robertson, and Dr. R. L. Lovvorn, nominated Dr. I. J. Johnson, State College of Agriculture, Ames, Iowa, as Chairman of the Crops Section for 1944, and Dr. E. N. Fergus and Dr. G. A. Wiebe as members of the Program Committee. They were unanimously elected.—L. F. GRABER, *Chairman, Crops Section.*

## NEWS ITEMS

DOCTOR WALLACE WORZELLA, formerly of the Department of Agronomy, Purdue University, has been named head of the Department of Agronomy, South Dakota State College, Brookings, S. D.

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DOCTOR HELMUT KOHNKE has been appointed Soil Scientist at the Purdue University Agricultural Experiment Station, Lafayette, Ind., with the rank of Associate Professor in the University. Doctor Kohnke has been conducting hydrologic research for the last several years with the Soil Conservation Service.

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DOCTOR WILMON NEWELL, Provost for Agriculture at the University of Florida, Gainesville, died on October 23, 1943. Doctor Newell had been Director of the Experiment Station and the Extension Service since 1920 and Dean of the College of Agriculture from 1920 to 1938 when he was made Provost for Agriculture. He was also Commissioner of the Florida State Plant Board.

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VOLUME I of an "Encyclopedia of Applied Plant Sociology" is to be published this month in a manuscript edition by the author, Morris J. Spivack, 95 West 46th Street, Bayonne, N. J.

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